

ISSUE 1 • 2018

ASH **at work**

Applications, Science, and Sustainability of Coal Ash

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On the Cover

From agriculture to high-tech applications, coal combustion products enjoy growing usage across the globe.



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Here's to the Next 50 Years

By Charles Price, ACAA Chair

When the National Ash Association—fore-runner to American Coal Ash Association—was formed 50 years ago, I suspect few people envisioned what the coal ash beneficial use industry would look like today. As Tom Adams points out in his Executive Director's message in this issue, beneficial use of coal combustion products increased from 17.5% in 1968 to more than 56% by 2016. Along the way, new types of coal combustion products have been added and the complexity of the industry has vastly increased.

For instance, scrubbers producing synthetic gypsum were research projects in the 1960s. Other emissions control developments over the decades—such as low-NOx burners, SCR and NSCR controls, and mercury control sorbents—have introduced a series of management challenges for ash marketers. These technological challenges were compounded by a regulatory environment that periodically provided challenges of its own. Regardless, the coal ash beneficial use industry has continued to grow steadily.

This raises an interesting question: What will the coal ash beneficial use industry look like 50 years from now? My prediction: very different once again.

Challenges for our industry continue to evolve. Although the size of America's coal-fueled power plant fleet has decreased, the demand for coal combustion products is on the rise and as a result, we face a very different situation than we encountered a decade or two ago. Today, we spend less time convincing people

that using coal combustion products is a good idea. (Users now embrace the performance and environmental benefits of our products and they want more.) We now spend more time on the logistics of meeting the supply for this increasing demand.

Strong customer demand for ash is rapidly expanding the menu of options available to ash marketers. In many respects, addressing prior-era ash supply issues was more challenging because customers tended to be more restrictive concerning ash quality and were less dependent on the material. The ash use market has now largely moved beyond seeing ash as an optional low-cost replacement for cement and other materials. The market now demands ash as an essential component for performance purposes. As a result, ash specifiers have become less restrictive regarding specific ash sources or arbitrary quality constraints, as long as consistency and performance can be demonstrated.

A host of strategies and technologies are now entering the market to address demand. To name a few:

- A variety of "reclamation" strategies can be used to harvest coal combustion products from the store of more than 1.5 billion tons of previously disposed ash. These strategies include ash beneficiation technologies (such as carbon removal) and less capital intensive reclamation techniques for sites where good-quality ash was discretely disposed before markets developed to utilize it.
- Ash blending strategies can be deployed to bring reclaimed ash or previously out-of-specification ash into the market.

- Bottom ash grinding strategies can be similarly deployed.
- As power plants that previously disposed of ash in wet impoundments convert to dry handling in response to new coal ash disposal regulations, new ash sources are becoming available.
- Use of natural pozzolans, either as a fly ash extender or a stand-alone replacement for ash, is under development in regions of the U.S.
- Opportunities for international ash imports are also under investigation.
- Finally, our industry's logistics network of transportation assets and storage facilities continues to grow with each passing year, adding more ability to move ash where and when it is needed.

If anything, this expanding menu of supply options is increasing the resiliency of the beneficial use industry—not degrading it. As supply sources both diversify and grow to include options where ash marketers can control their own manufacturing rates, the beneficial use industry will become less dependent on supply sources potentially subject to interruption or shutdown. As ash users see supply reliability increase, they will feel more confident in increasing their usage.

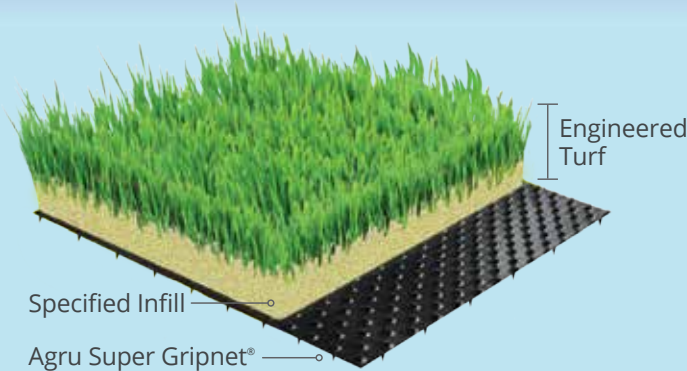
Which leads to one other interesting question: What percentage of coal ash utilization is possible above today's 56%?

The first 50 years of ACAA's existence proved that the coal ash beneficial use industry is adaptable, resilient, and committed to continuing expansion. I am confident that the next 50 years will see that trend continue. ♦

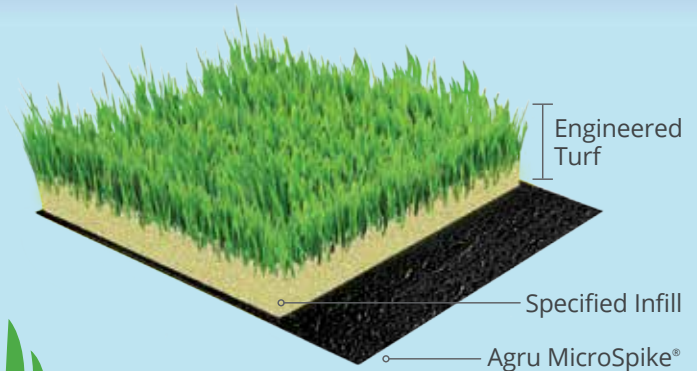
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Happy Birthday, ACAA!

By Thomas H. Adams, ACAA Executive Director

On March 8, 2018, the American Coal Ash Association (ACAA) turned 50 years old. A half century ago on that date, a Certificate of Incorporation was recorded in Washington, DC, for the National Ash Association (NAA). The NAA changed its name to the American Coal Ash Association on April 19, 1986.

What were some of the major news stories in 1968?

- The Vietnam War Expands and Rages On
- Dr. Martin Luther King, Jr., and Senator Robert F. Kennedy Assassinated
- Richard Nixon Defeats Hubert Humphrey and George Wallace for the U.S. Presidency
- Civil Rights, Anti-War, and Feminist Groups Take to the Streets to Protest
- The U.S. Repeals the Gold Standard Requirement
- CBS Debuts 60 Minutes

And 50 years later, some of the major news stories are not all that different.

- War Rages On Throughout the Middle East
- Controversy Rages Over the U.S. Presidency
- Protest Groups Fill the Streets Demanding More Government Benefits, Restriction of Gun Rights, Equal Rights for the LGBTQ Community, and Open Borders
- Bitcoin: An Alternative to Government-Issued Currency?
- 60 Minutes Is Still on the Air

While the U.S. has been dealing with these issues over the last five decades, the ACAA has made great progress in advancing the beneficial use of coal combustion products (CCPs). In 1968, disposal of CCPs was much easier and cheaper than engaging in most beneficial uses. Over time, with the recognition that ponds and landfills were getting harder and harder to permit, construct, and manage, progressive utilities and coal ash marketers began to build an industry to advance the idea that disposal was not the only solution to CCP management. ACAA CCP Production & Use Surveys provide the data to demonstrate how far we have come. The data in the table to the right show survey results from our founding in 1968 to our 25th birthday in 1993 to our most recent survey data for 2016.

Clearly, we are fulfilling our mission. Beneficial use of CCPs is growing. We *are* benefiting the environment. At the same time, we *are* filling legitimate commercial needs with a technically viable solution. We *are* contributing to a more sustainable society.

As we celebrate the accomplishments of our first 50 years, we can also look to the possibilities of the next 50. Too much CCP is still sent to disposal, and there remains a significant gap between supply and demand for some CCPs. Demand for concrete-grade fly ash and FGD for wallboard, for example, is running well ahead of supply.

Using the data from our surveys, it appears that a conservative estimate of the quantity of CCPs in disposal across the U.S. exceeds 2 billion tons. Some of this volume of CCPs in landfills and ponds across the U.S. will be reclaimed for beneficial use. Technologies under development will provide new opportunities to use CCPs. Some of these new opportunities are old ideas whose time has arrived. Some are new ideas, such as rare earth element extraction.

The industry leaders who had the wisdom to come together to establish the National Ash Association and begin this journey deserve our gratitude. We also must thank those who have led this work through our first five decades—as well as those who continue to support and lead this effort today. Let's take a minute to reflect on our success and then get back to work. We see what can be done when we act together. The future awaits our best efforts.

	1968	1993	2016
Fly ash used, %	9.5	22.0	59.9
Bottom ash used, %	24.7	29.8	37.3
Boiler slag used, %	57.7	55.0	59.1
FGD used, %	0.0	5.8	57.4
Total CCP used, %	17.5	21.8	56.0

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An Acoustic Skin of FGD Gypsum for Hamburg, Germany's Top-Class Concert Hall

By Hans-Joachim Feuerborn

Elbphilharmonie Hamburg owes its unique acoustics to the “white skin” of panels made from FGD gypsum.

SOURCE: Elbphilharmonie Hamburg/Michael Zapf

A new concert hall, *Elbphilharmonie*, opened in January 2017 in Hamburg, Germany, and has quickly become a popular attraction for concertgoers and tourists. Swiss architecture firm Herzog & de Meuron designed the building, whose lower floors were previously used as a warehouse. Notably, the interior of the hall features a skin made from wallboards of FGD gypsum to achieve the desired acoustics.

The warehouse was internally demolished and the foundation improved with concrete piles. In total, 63,000 m³ of concrete was produced using more than 4000 metric tons of fly ash. Approximately 12,000 m³ was needed for the foundation and 51,000 m³ for the concrete skeleton. A further 41,000 m³ had to be produced for use as exposed concrete, walls, stairways, and elevator trays—resulting in exacting requirements for formworks and homogeneity of the concrete.

The new building would eventually arise from the brick foundation like a cockscomb. Inside, concrete products form the center of the concert hall. A maximum of 2100 concertgoers can be accommodated on different levels resembling the terraces of vineyards. They

are arranged not symmetrically, but rather in rows of different sizes, resulting in smaller terraces, protrusions, and balconies. The highest point is 17 meters above the stage and all seats are located within 30 meters of the conductor.

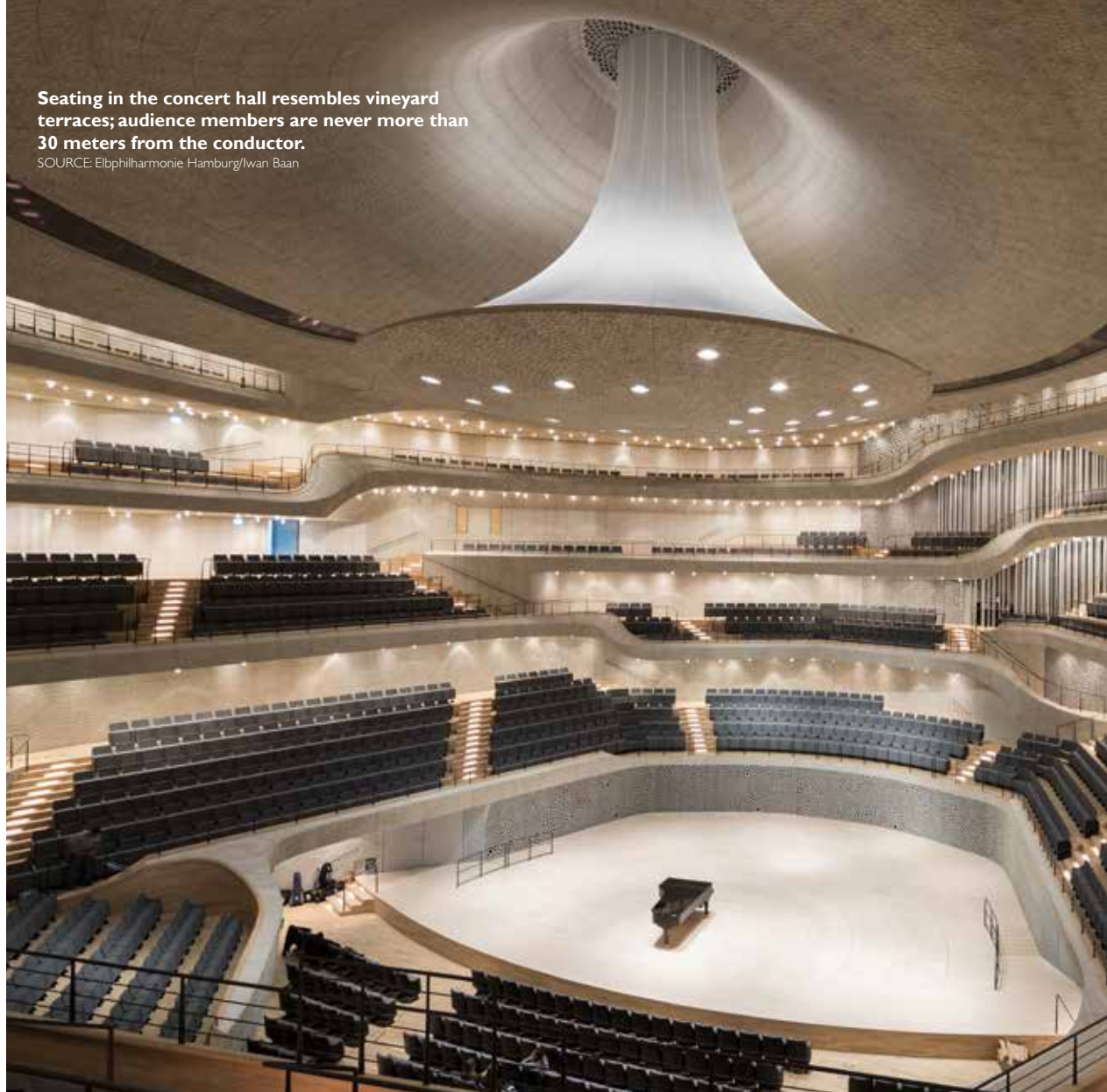
The concert hall is distinguished not only by the proximity of the musicians to the audience but also by its unique acoustics. To optimize the acoustics, the architects “decoupled” the concert hall from the building via the use of 362 steel springs. Both the Grand Hall and the Recital Hall are acoustically autonomous spaces, with the steel spring elements acting to buffer the concrete shell from the outside world. Outside sounds do not penetrate the halls’ interior, and inside sounds do not escape outside.

Herzog & de Meuron commissioned the Japanese acoustician Yasuhisa Toyota to optimize the design for both fire protection and acoustics. Toyota calculated the acoustics of the hall using complex three-dimensional models, ultimately building a one-tenth-scale replica for testing. Based on the results, he developed a “white skin” out of 10,000 gypsum fiber boards with FGD gypsum to cover the walls and ceiling.



Seating in the concert hall resembles vineyard terraces; audience members are never more than 30 meters from the conductor.

SOURCE: Elbphilharmonie Hamburg/Iwan Baan



Using custom software, Toyota designed the surfaces of the panels to avoid interference and to scatter the sound to optimally fill the concert hall space. This necessitated the use of gypsum fiber boards, as the material is fire-proof, possesses the optimal density, and the surface could be customized by milling. With the help of an expansive reflector that is suspended from the middle of the vaulted ceiling, the panels project sound into every corner of the space.

Ultimately, the acoustic panels were manufactured by Knauf Integral, in Munich. Elements of 18 cm thickness with a weight of up to 150 kg/m² were produced. The surface was milled with CNC technology to prepare more than 1 million seashell-like valleys with a depth of 5 to 9 centimeters—resulting in 10,287 elements, all different in texture.

The gypsum is called Gifatec and consists of a 90% mixture of FGD and natural gypsum and 10% cellulose fibers. The slurry of gypsum and cellulose is conveyed in a thickness of 2 cm and dewatered. Afterwards, it is rolled up to a defined thickness and roughly cut. After maturing, the

plates are dried in an oven, refined to their final thickness, and milled. Then they are coated and palletized. The process results in homogeneous density of the plates.

This report is based on technical information provided by WIN—Wirtschaftsverband Mineralische Nebenprodukte e.V.—a German trade association for CCPs and a member of ECOBA. The association promotes the use of mineral by-products from thermal processes as secondary raw materials in the economic cycle. Further examples of beneficial uses of CCPs as construction materials can be viewed on ECOBA member websites that can be found at www.ecoba.com. ♦

Hans-Joachim Feuerborn has served as Secretary-General of the European Coal Combustion Products Association (ECOBA) since 2008. In 2000, he began working as an adviser on environmental issues at VGB PowerTech—the European Technical Association for Power and Heat Generation—where he has focused on the by-products from coal- and biomass-fired power stations.

Utilizing the UK's Vast Landfilled Fly Ash Deposits

By Dr. Nigel Cooke

In the late 1990s—when I first became involved in fly ash—the challenge for companies such as Blue Circle Industries and Scottish Power (via ScotAsh) was to seek markets to minimize the landfilling of fly ash produced by coal-fueled power stations. My role was to help drive and expand markets for fly ash in areas such as grouts, the oil sector, stabilization products, and engineering fill, through to established markets such as bricks and blocks. Our focus then was on growing market opportunities and minimizing landfill, not on protecting future supplies.

Despite all our efforts to develop markets for fly ash, we still saw some 30 to 50% of the fly ash produced going to landfill. As a result, industrial landscapes that surround coal stations are dominated by large stockpiles of ash. These stockpiles are not immediately apparent to the public, as some have been built on and others are now flourishing nature reserves.

However, the current shift in energy policy toward renewable and low carbon means the production of coal ash has been in significant decline and changed the market dynamics considerably. For example, between April and June 2017, coal accounted for a mere 2% of our energy consumption in the UK—a figure

few could have predicted back in the 1990s. To put that in context for the ash industry: in 2012, UK coal stations were producing around six million metric tons of fly ash with some 50% used in the construction sector and the remaining 50% directed to landfill. In 2016, only 1.6 million tons of fly ash were produced—a decline of over 70%. By 2025, this could fall to zero.

Major infrastructure projects such as the Hinkley Point Nuclear Power Station and HS2 (high-speed rail network from London to the north) are also under scrutiny in terms of providing sustainable, low-CO₂ solutions. This includes focus on the long-term durability of concrete and the products used in such structures. When it comes to durable concretes and concrete products, both blast-furnace slag and fly ash have important roles to play, as both can enhance durability. While slag can replace fly ash for many applications, there are finite supplies of blast-furnace slag and prices are constantly rising. This has generated a strong interest to identify new sources of fly ash.

University Challenge

The UK Quality Ash Association (UKQAA) has been working with the University of Dundee's Concrete Technology Unit (CTU) since 2014 to develop a better understanding of the contribution that can be made by landfill deposits of fly ash. The main aims of this partnership include understanding the characterization of different deposits of landfill ash, comparing the physical and chemical properties of landfill ash with fresh ash, understanding the impact of processing on the performance of landfill ash, and comparing the performance of landfill ash with fresh ash in concrete.

The UKQAA's view is that stockpiled ash should be designated as future “pozzolanic” reserves. It has been reported that there are more than 50 million tons of landfill ash potentially in reserve. Clearly, with the changing situation, it is in everyone's interest to try to produce a more precise figure on a regional basis. If landfill ash can perform in a similar manner to fresh ash in terms of concrete performance, this can result in a significant benefit and opportunity for the construction industry. Moreover, something that



Between 2012 and 2016, the amount of fly ash produced by UK coal plants dropped 70%.

SOURCE: UKQAA

is designated a waste could theoretically be incorporated under a minerals plan and make a positive contribution to the economy rather than being a potential liability.

The initial results from the Dundee CTU project have been encouraging and demonstrate that landfill ash can be used as a cementitious component in concrete. The Dundee CTU has also demonstrated that the performance of the concrete can be enhanced through further processing of the ash, such as by fine grinding, although clearly there is an associated cost.

Dundee, working in collaboration with U.S.-based ST Equipment and Technology, has also been able to remove carbon from the landfill fly ash to meet EN450-1 specifications (for quality fly ash). Other technology providers, such as SCB, also claim that they can remove carbon through their technology and are in detailed negotiations with a couple of U.S. utilities. The fact that there are choices of technology can only be good news for UKQAA members.

With regard to scientific studies, there are still questions over the water demand and activity index of landfill ashes tested when compared to “fresh” ashes. This is hardly surprising, and it may require a revision of standards geared toward landfill ash. A further stage in the development of the Dundee project requires the evaluation of how landfill ash may impact different aspects of concrete durability. The key message the UKQAA would like to convey is that the results are sufficiently encouraging to continue with this valuable project, and clearly the potential opportunities are considerable.

While focus is often on the use of fly ash as a key component in cements, concrete, and concrete products, making available sources of landfill ash for use in grouting, ground stabilization, and aerated concrete blocks is also of major interest to UKQAA’s members. Grouts and aerated concrete blocks can account for an annual demand of over 1.5 million tons of fly ash, and while the replacement of the fly ash by sand is an option, the performance of sand falls below that of fly ash and it is much less sustainable.

Designating landfill ashes as future “pozzolanic” or “mineral” reserves will require support from government agencies along with the owners of the stockpiles. Furthermore, although there are regulatory frameworks and policies in place to support the use of “fresh ash” sourced from coal-fueled power stations, the development of landfill ashes as future pozzolanic reserves will need to address both standards and licenses to facilitate their extraction. To tackle this, the UKQAA and CTU are working with the UK’s Environment Agency and other stakeholders to assess what processes, regulations, and policies need to be addressed to facilitate landfilled ash extraction.

When it comes to identifying the potential volumes of fly ash deposited within landfill sites and lagoons, it will be important to take a pragmatic view of the feasibility of extraction. This applies to sites that may have been handed over as nature reserves or community access and sites that might be earmarked for future light industrial use. Having said that,



Work by the UKQAA and the University of Dundee’s CTU shows that landfill ash can be used as a cementitious component in concrete.

there are significant fly ash deposits associated with power stations that are still in operation or have only recently been closed. Through our work with the CTU and our members, UKQAA aims to map these locations and identify the opportunities and challenges that each site faces—from logistics to community impacts. It is a big challenge—one that not only safeguards future supply but can even drive investment in a new sector.

Beyond our Shores

While extraction has huge potential, it is not the only area the UKQAA membership is investing in; importation is a growth area as well. In the short term, we are likely to continue to import fly ash from across Europe, although Western Europe is moving away from coal also. As a consequence, UKQAA members are beginning to explore potential sources farther afield, including Eastern Europe, Asia, and the Far East.

We expect importation to continue to grow to meet demand over the next few years, but in the long term we would like to see landfill extraction perform a greater role in fly ash supply. It is not only a sustainable way to make use of a secondary resource, but it also helps boost industrial growth in the UK—in everything from skills investment to the use of new technologies.

The last few years have been tough in the fly ash sector with rapid coal closures—and the rise of renewables—impacting supply faster than anyone could have expected. This has resulted in the UKQAA taking time to re-evaluate how it can add value for its members and ensure that the construction sector continues to have access to this vital and versatile material. It is an exciting time and a chance to drive real change that benefits the construction industry and its multitude of suppliers. For more information, please visit www.ukqaa.org.uk. ♦

Dr. Nigel Cooke joined the UKQAA in June 2017 as Director. He has over 30 years’ experience in the building materials sector, including roles with Blue Circle Industries and Lafarge. Dr. Cooke has responsibility for representing the UKQAA and its membership to industry, actively promoting the use of coal ash and biomass ash from UK power stations.

The Effect of Land Application of Sludge Stabilized with Coal Fly Ash and Lime on Soil and Crop Quality in Israel

By Dr. Pinchas Fine and Dr. Uri Mingelgrin

This paper summarizes the benefits accrued from the agricultural use of sludge stabilized with lime and coal fly ash (N-Viro Soil™, or “NVS”) (Logan and Burnham 1995; Teutsch 2018, this issue). Considerable practical experience has already been accumulated regarding the use of NVS in Israeli agriculture. The data and conclusions as follows are based on observations recorded in numerous experiments and commercial applications of NVS, and they demonstrate both the benefits and potential risks associated with its use. Whenever possible, comparison to the effect of application of other types of treated sludge (most often composted sludge) is offered.

Israeli NVS typically contains 50 to 60% sewage sludge (excess activated from a secondary biological treatment stage), 5 to 10% burnt lime, and ~40% coal-firing fly ash (all on a wet-weight basis). Its initial pH is high (~12.5) and in a pile it will remain so for weeks. However, after addition to the soil and wetting of the field by rain or irrigation, the pH value quickly drops (within hours or a few days) to return to that of the soil before NVS application (Oka, et al. 2006a,b). The extent of the rise in soil pH depends on the nature of the NVS product, the application load, and the soil properties (Ben-Yephet, et al. 2006). Due to the elevated pH, a negative impact of NVS application was expected in the semi-arid, calcareous Israeli soils, specifically a decline in the phytoavailability of phosphorus and of cationic trace elements. Yet this was proven wrong by the results of numerous laboratory and field experiments, both for calcareous and for non-calcareous soils.

A negative phenomenon often encountered is the occurrence of small, hard NVS crumbs that remain on the soil surface following NVS application. The formation of these aggregates is a result of the pozzolanic nature of the ash, and they eventually slake following their incorporation in the soil in subsequent years. Increased familiarity with NVS will enable its use for most crops and under most environmental conditions in a beneficial manner and without a negative impact.

In commercial use, NVS is used mainly as a substitute for fertilizers in field crops, and the considerable experience accumulated is very encouraging—with zero problems (or complaints) after five years of application on about 3500 ha, including in long-term field experiments (3 to 5 years with annual applications of regular-to-heavy loads; Fine, et al. 2015a). Other uses of NVS

are for combating soil-borne plant pathogens and pests and as an ameliorator of clayey natric soils. The biocidal effect of NVS results from gaseous ammonia formed in the soil during the period of transient high pH immediately following application. The ammonia sources are both the organic nitrogen contained in the NVS itself and added ammonia-bearing fertilizers. In cases in which soil disinfection is the purpose of the application, heavier NVS loads are applied to achieve both high soil pH and ammonia concentrations. Under such circumstances, soil self-ventilation will reduce ammonia concentrations; however, soil leaching might be needed at times to reduce salinity level in the soil.

An economic analysis has demonstrated that the return to farmers from applying NVS, mainly as a source of nutrient (NPK and micronutrients), is about US\$260 per acre assuming NVS supply free of charge at the field (as is the case in Israel), thus contributing significantly to profitability (Hadas, et al. 2015).

Benefits Associated with Producing NVS as Compared to Composting

Benefit for the Urban Sector

Pasteurizing sludge by mixing with lime and coal fly ash is applicable to any dewatered type of sludge, including untreated sludges (primary-settled and secondary-biological) that are difficult to compost. This allows major savings (about 50%) in the infrastructure and operational costs of wastewater treatment facilities.

Direct Benefits to the Environment

- Composting is a source of greenhouse gas (GHG) emission (CH_4 or N_2O) and ammonia volatilization, while these do not occur in the N-Viro process.
- Industrial manufacture of nitrogen (N) fertilizer emits GHG (Fine and Hadas 2012). Sewage sludge is a source of available plant nutrients, and its GHG abatement potential depends on the degree of nutrient preservation in the final product. While composting volatilizes ~50% of the N contained in sludges (40 to 70 g N/dry metric ton), the NVS process preserves almost all of it and does not impair its phytoavailability (Fine, et al. 2015, slide 6).
- The use of NVS enables a reduction in the amount of pesticides used for vegetable crops in sandy soils.
- NVS turns two by-products (sludge and fly ash) into a desirable agricultural resource, thus reducing the mining of

non-renewable resources (for example, apatite as a raw material of phosphorus [P] fertilizer).

Benefits to Agriculture

- NVS is a source of essential nutrients—nitrogen, phosphorus, potassium, and micronutrients, as well as of organic carbon (Ibid.):
 - **With respect to organic nitrogen:** Phytoavailability (via microbial degradation) is considerably higher in NVS than in sludge composts. This reflects the preservation of the sludge's high N bioavailability in NVS as compared to the extensive biodegradation that compost undergoes during the process of its maturation.
 - **Phytoavailability of sludge phosphorus:** The potential P phytoavailability was similar for NVS and sludge compost. This was shown for the products themselves (by extraction in water suspensions; Ibid., slide 7) and in the field (as reflected by crop response and soil tests). Still, PO_4 concentrations in the soil solution under NVS application are lower (yet adequate to plant needs) because of the latter's higher Ca^{2+} release into soil solution. Thus, the more controlled release of phosphorus in NVS-treated soils is a further advantage in P-vulnerable environments.
 - **Phytoavailability of micronutrients:** The concentration of micronutrients (for example, iron, zinc, manganese, copper, molybdenum, etc.) was always in the normal range under application of both NVS and sludge composts in all the crops that were tested (including potatoes, carrots, lettuce, corn, wheat, sweet potatoes, sunflower seeds, peanuts, and various legumes). However, molybdenum concentration was often much higher in plants following NVS application (owing to its fly ash component). The enhanced molybdenum availability had a strong positive effect on the yield of some crops (especially legumes).
- NVS improves the physicochemical properties of soils, especially sodium-affected ones. These positive effects emanate from the pozzolanic nature of the ash, the prevalence of silt-sized particles in coal fly ash, the presence of lime (and the resulting Ca release), and the presence of soluble organic matter and NH_4^+ . Following NVS application, processes such as carbonation and pH drop enhance the availability of nutrients originating from either the organic or mineral (ash and lime) constituents of the NVS and improve the soil properties (for example, reduction in the exchangeable sodium percentage [ESP] value). The following phenomena were detected following NVS application:
 - **Reduction of soil sodicity:** In a laboratory leaching study, a sodium-affected, silty sand soil was mixed with several additives. The relative efficiencies in reducing the ESP value were in the following order: gypsum \geq NVS $>$ digested sludge \approx distilled water $>$ sludge compost.
 - **"Soil thinning":** In a field experiment, fly ash was applied to the top 20-cm layer of a clayey (smectitic) sodic soil at the rates of 200 and 800 tons/ha. This completely arrested swelling and shrinking of the soil and improved soil tilth and thus its quality as seed bed (refer to Figure 1).
 - **Soil aggregate stability:** NVS (at a rate equivalent to 200 kg nitrogen/acre) significantly increased the stability of soil aggregates in three soils (a silty, a clayey, and a silty sand soil) in a pot experiment. Sludge compost and anaerobically digested sludge had no appreciable effect, yet all three additives improved hydraulic conductivity of the silt and clay soils and decreased it in the sandy soil.
- **Control of wind erosion:** A tunnel simulation study on matured sand/fly ash mixtures showed that while pure sand detached already at a wind velocity of 9 m/sec, the sand/fly ash counterpart displayed significant erosion only at a wind speed ≥ 26 m/sec.
- **Reduction in crust formation in vulnerable soils:** Calcareous loessial soils with a somewhat sodic upper layer (which are abundant on desert fringes) tend to form crust upon wetting, thus enhancing runoff. Fly ash application considerably weakened the crust and, at 15% w/w application rate, the rate of water penetration increased 2.5 times under simulated rain, thus reducing runoff appreciably.
- **"Thickening of sand and sandy soils":** Adding fly ash (mainly silt-sized particles) to sand changes the particle size distribution of the receiving sand. Experiments in a rain simulator showed that enrichment of dune sand with fly ash at up to 15% (w/w) increased the water-holding capacity of the sand up to eight-fold as compared to an unamended control.
- NVS suppresses weeds, soil-borne plant pathogens, and pests and reduces the extent of disease symptoms.

Gaseous NH_3 is biocidal (Lazarovits, et al. 2001). The temporary increase in pH upon NVS application was used to bring about the conversion of mineralized and/or added NH_4^+ into the biocidal gaseous NH_3 form. This was performed in a large number of field experiments conducted over the last decade in Israel. The pesticidal efficacy of the NVS- NH_3 treatment was higher in sandy soils, at high soil temperatures, and at initially elevated soil solution pH. The target pH value is $\geq \text{pKa}$ of the $\text{NH}_3/\text{NH}_4^+$ system, and the NVS load was determined accordingly (Zasada 2005; Zasada and Tenuta 2004; Oka, et al. 2006a,b; Fine 2015, slide 11).
- NVS application for purposes of plant protection (as well as for determination of uptake of heavy and trace elements and of other agronomic aspects) was tested in carnations and in food crops, including potatoes, lettuce, carrots, bell peppers, and peanuts. In addition to weed control (refer to Figure 2), massive reduction was usually observed in populations of *Streptomyces* and *Fusarium* species (including pathogenic species such as *F. oxysporum* f. sp. *Dianthi*, *Verticillium dahlia*, *Rhizoctonia solani*, *Sclerotium rolfsii*, and root-knot nematodes (Ibid., slides 12-22). However, while NVS + NH_3 significantly reduced "deep-pitted scab" (caused by *Streptomyces*) in peanuts (four field experiments; Ibid., slides 14-15), it significantly intensified the occurrence of the "mesh phenomenon" (brown mesh markings on the outer nut shell), the cause of which is yet unknown.
- NVA contributes to the yield of food and fodder crops. NVS application was tested on a wide variety of crops, including fodder (corn, wheat, barley, vetch/clover, and peas) and food crops (potatoes, carrots, lettuce, sweet potatoes, chickpeas, bell peppers, and sunflowers). Application rate was based on

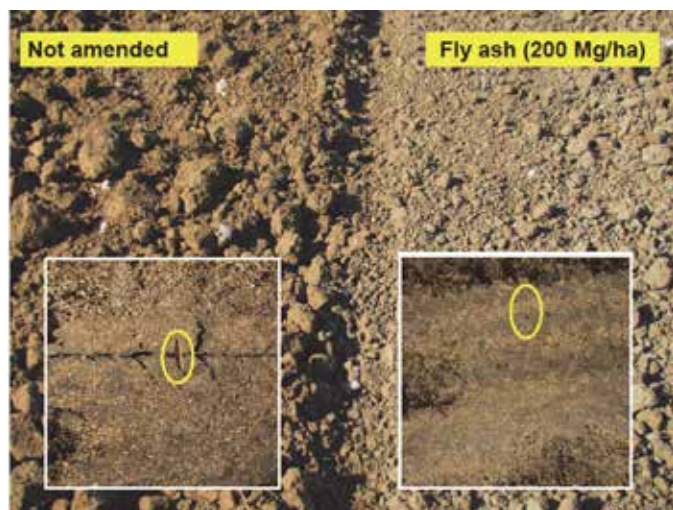


Figure 1. A clayey (smectitic) sodic soil ploughed in with coal-firing fly ash at 200 metric tons/ha⁻¹. Shown are the effect on cracking after soil drying in the summer of the following year (smaller frame), and the effect on the size of soil crumbs of the seed bed five years after treatment (larger frame).

the nitrogen dose and was equivalent to 500 kg total N/ha (≥100 metric tons NVS/ha) or more.

The fodder crops were tested for the NVS role as fertilizer substitute (Ibid., slides 8-10; Fine, et al. 2014). At the above N load and given the quality of the NVS sludge component (secondary aerated), the yield of drip-irrigated corn after four consecutive annual NVS treatments was 80% of the yield in a commercial control. However, on low-fertility soils, NVS often increased yields several fold (for example, potatoes and barley in sandy soils and vetch/clover in a shallow calcareous soil) compared with sludge compost (at the same N load) or with a commercial control. The main cause of the higher yield was the improved N availability and micro-nutrients supply (Fine, et al. 2015, slides 23-25). The potatoes grown on the NVS-treated soil, which were also fertilized in excess, displayed an elevated Ca content in the tubers (a positive outcome).

Environmental Concerns

Concerns were raised regarding potential deleterious effects of the addition of coal fly ash (a major component of NVS) to soils. Below is an evaluation of these concerns:

- **Leaching of nitrogen below the root zone:** All the nitrogen in NVS is organic and therefore is a slow-release N fertilizer less prone to leaching than mineral N forms. This sludge N is bioavailable to a large extent, as it was not yet stabilized as was the nitrogen in compost. The higher N availability and yields of wheat and barley grown on NVS on sandy soils were due to reduced N leaching compared with leaching from soils amended with commercial fertilizer and to higher N phytoavailability compared with compost.
- **Leaching of toxic elements:** This was refuted in a lysimeter study (Ibid., slides 26-30). The concentration of trace and toxic elements in the leachates from three soils amended with NVS was often below detection (~1 µg/l), or there was no difference in the leaching of the toxic elements compared to controls.
- **Content of non-essential trace and heavy metals in crops:** The concentrations of arsenic, cadmium, lead, nickel, and other



Figure 2. Effect of coal-firing fly ash and NH₃ application on weed emergence. The three beds on the right were ploughed in with fly ash (100 metric tons/ha⁻¹) and ammonium sulfate (2.8 metric tons/ha⁻¹ ≈ 250 mg N-NH₄⁺ kg⁻¹ soil). These beds and the bed in the front (which is dominated by *Portulaca oleracea*) were covered with clear plastic for a week to allow for soil heating. The beds on the left were not treated and are dominated by *Amaranthus palmeri*. The other parts of the field were not irrigated.

elements of concern were measured in the many aforementioned crops, in field experiments and commercial observations (Ibid., slides 24-28). No accumulation of such elements was observed.

- **Potential long-term negative effect of adding fly ash to agricultural soils:** Several outdoor (field and lysimeter) experiments that provide a conservative simulation of the long-term effect of application of NVS were conducted. Such was, for example, the attempt mentioned previously to improve a sodic-clayey soil by addition of fly ash. Fly ash was ploughed in at extremely high rates of 200 and 800 metric tons/ha⁻¹; these quantities are equivalent to the fly ash added in 7 and 28 agronomic NVS applications, respectively. The corn sown a few days after the fly ash incorporation showed no sign of damage, and the concentrations of trace and heavy elements in the stover and seeds were at the normal range with an increase of chromium concentration in the grains at the higher load (yet still in the normal range, which is desirable—Cr being an essential element in the human diet with an RDA of 50 to 200 µg). Molybdenum concentration increased in the corn stover under both rates of fly ash application, as it usually does in crops following the application of manures. In the following two years, no difference in the elements' concentration was observed between plants (corn and chickpeas) grown on the fly ash-loaded soils and on the non-amended controls.

Conclusions

Based on the aforementioned, it is apparent that application of NVS at rates expected in agricultural fields will not cause an undesirable change in the physical and chemical properties of almost all soils. This was demonstrated with Mediterranean soils that encompass a very wide range of physical and chemical properties. Application of NVS (and fly ash) in agriculture provides many benefits, such as replacing commercial fertilizers, improving soil quality, and suppressing weeds and plant diseases. Proper use of NVS improves the profitability of farming and the quality of the products, reduces costs to the urban

sector, decreases risks to the environment, and reduces the mining of diminishing resources. Yet, despite the low likelihood of long-term negative effects due to the repeated application of NVS or coal fly ash, it is necessary to continue to monitor the impact of the application on the properties of agricultural soils.

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Global Trends in Coal-Fueled Power Generation and the Need for CCP Imports to the Americas

By William Stanley and Rick Haverland

Traditionally, coal combustion products (CCPs) sourced from domestic coal-fueled power stations have met the U.S. demand for reliable and cost-effective materials in a wide range of commercial applications. This article will focus on recent changes in global supply dynamics of CCPs and the projected impact on the portland cement, concrete, and gypsum wallboard markets in the U.S.

In 2011, under the authority of the 1990 Clean Air Act, the Environmental Protection Agency (EPA) proposed sweeping new limits on hazardous air pollutants (HAPs) that could be released into the atmosphere from coal-fueled power plants. During this period, the U.S. Energy Information Administration's (EIA) initial estimates of coal-fueled plant closures directly related to environmental compliance issues ranged between 10 and 20% of the total U.S. coal-fueled generating capacity. However, EIA's early projections for plant closures did not account for the additional impact of low-cost, plentiful natural gas on total coal-fueled plant retirements and conversions. The revised projected closure/conversion estimates are up to almost 40% as compared with 2011 coal-fueled capacity, to the point where natural gas has recently surpassed coal as the leading source of electricity in the U.S.

In 2012, in anticipation of the impending structural changes in U.S. supply of CCPs for its own domestic portland cement, concrete, and wallboard customers, ZAG International established long-term, offshore supply positions for fly ash, bottom ash, and ultimately flue gas desulfurization (FGD) gypsum. In addition to summarizing the global supply trends for CCPs, this article will also address the technical and commercial considerations for importing CCPs to North America from offshore locations.

Global Trends in Coal-Fueled Power Capacity

U.S. Outlook: Today, the U.S. continues to announce closures of financially troubled and older coal-fueled power plants even as government officials work on a bailout plan to keep them operating. In addition to the compliance pressure to meet EPA's National Emissions Standards for Hazardous Air Pollutants (NESHAP), the most recent drivers for the accelerated closure rates in 2018 (refer to chart on the following page) have been coal's displacement by natural gas, which is projected to remain a low-cost and environmentally

acceptable alternative to coal for the foreseeable future. Consequently, from 2010 to 2017, coal's share of U.S. electricity generation dropped from approximately 45% to 30%.

Natural gas' growing prominence as the leading low-cost source of U.S. electricity is due to its long-term abundant supply, coupled with ongoing technological advancements in hydraulic fracturing ("fracking") and horizontal drilling. These new techniques now allow drillers to harvest oil and gas reserves that previously were cost prohibitive under traditional drilling practices. Competitive regional electricity markets throughout the country have also driven users to look at low-cost options and, consequently, many power generators will continue to transition from coal to natural gas.

The coastal geographic regions of the U.S. such as the Northeast, Southeast, U.S. Gulf, and West Coast have been particularly hard hit by the coal-fueled generating plant closures, with 2018 projected to retire approximately 15,000 MW of capacity.

Europe: In 2009, the European Union (EU) enacted legislation intended to expand renewable energy by 20%, reduce greenhouse gas emissions by 20%, and achieve a 20% increase in energy efficiency by 2020, known as the "20-20-20" targets. While there was a growing emphasis on finding renewable alternatives to coal-fueled electricity, coal's share of capacity actually increased until around 2013. As such, Western Europe remained a dominant exporter, and supply opportunities for CCPs from European sources remained relatively abundant.

Beginning in 2013, the EU's Large Combustion Plant Directive (LCPD) forced older and higher-polluting plants to shut down. The successor to the LCPD, the Industrial Emissions Directive (IED), will result in even more stringent emissions limits. Older coal-fueled power plants will have to meet tighter environmental standards by 2023, and the UK has committed to phase out all coal-fueled generators by 2025.

In 2014, the "20-20-20" targets were further revised to 40-27-27 targets, which are forcing many older plants to consider closing due to the costly process modifications necessary to comply with the stricter air quality standards.

Germany: Since 2010, German coal-fueled generation has been competitive relative to natural gas-fired generation based on falling coal prices, lower CO₂ emission costs, and increasing natural gas prices. Consequently, between 2010 and 2014 production from coal-fueled power plants increased while gas and nuclear power generation contracted. The fuel switch from gas to coal due to low-cost coal-fueled power plants served as an interim baseload capacity while renewables were still in the developmental stages. The interim fuel strategy was especially important to Germany's nuclear phaseout plan following Japan's Fukushima disaster. During this period, the increase in coal-fueled generation resulted in seasonal excess inventories of CCPs for export to other countries and served as one of ZAG International's earlier fly ash sourcing options for the U.S. and Europe.

In 2015, the German government introduced a series of measures to reduce CO₂ emissions, and the energy policy continues to evolve toward a heavily weighted renewables emphasis moving forward. Since the implementation of these policies, CCPs are now in short supply and primarily consumed within the regional commercial markets, notably Scandinavia.

The Netherlands: The Netherlands is Europe's second-largest producer of natural gas, after Norway, with much of the supply utilized domestically. Although the country has installed 3000 MW of coal-fueled power capacity since 2014, its government is committed to the EU and international climate action. It will participate in the EU strategy and attempt to reduce CO₂ emissions 17% by 2030 and 60% by 2050.

As of late 2016, the Dutch parliament voted to support the closure of all unnecessary coal-fueled generating capacity to meet its Paris climate commitments. Between 2012 and 2014, CCPs from this region supplemented the German fly ash export supplies to the U.S. However, since then, CCP supply has been limited to distribution within regional markets.

United Kingdom: Further complicating the global supply picture for CCPs, in November 2015 the UK government announced a commitment to phase out the use of coal-generated electricity by 2025. This planned coal phaseout represents a multi-decade trend away from coal that started with investments in natural gas plants and then renewables. In recent years, the UK has become a net importer of concrete-grade fly ash and is served by regional supply sources from Europe and Turkey. Furthermore, the UK has committed to a major nuclear power plant with Chinese participation.

Italy: In October 2017, the Italian government, as part of the National Energy Strategy, announced a plan to phase out coal-fueled generation by 2025. While the strategy was signed on November 10, 2017, it is non-binding and will need to be

A big new wave of coal-plant retirements is expected this year, driven primarily by economics, that will rival the scale of closures in 2015. Many of these imminent retirements were only announced in 2017.

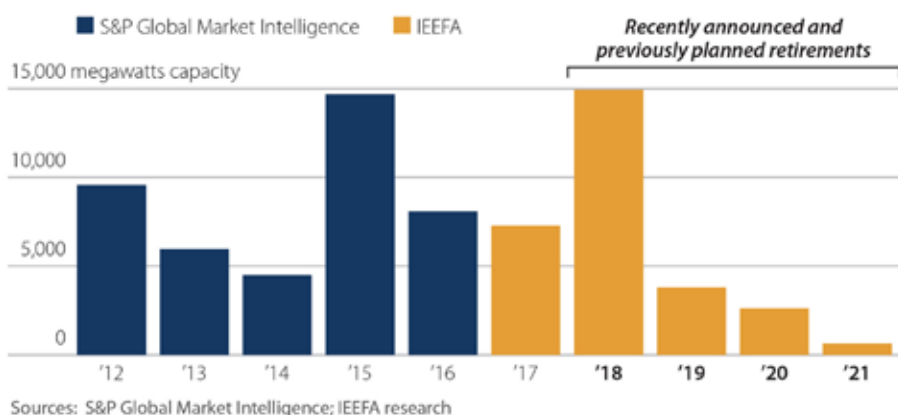


Figure 1. Coal-Fired Electric Generation Retirements

implemented through future executive measures.

Historically, Italy has exported its annual excess CCP volume to the U.S. and throughout the Mediterranean region for cement manufacturing, concrete, and gypsum wallboard applications. ZAG projects that while supply availability from this country may decrease somewhat in the future, it should continue to remain an option in the intermediate term. The key question is how reliable this will be due to the unstable political and economic situation in Italy.

Spain: Although natural gas is the single leading fuel in Spain's power mix, the combined contribution from renewables (wind, solar, and hydro) already supplies approximately 50% of Spain's total electricity generation. While coal power generation supplies approximately 10% of Spain's electricity, CCPs for export have been available from time to time on a "spot" basis based on local commercial market demand. Here again, reliability of supply is a challenge.

India: By 2020, India is expected to be the world's third-largest energy consumer behind the U.S. and China. Currently at almost 60% of the total power mix, coal will continue to be the leading power-generating source in India in the future. The government is also focusing on renewable and nuclear capacity development, with the intention of diversifying the country's power mix and reducing carbon emissions.

Turkey: Turkey is one of the few countries that is actively planning to expand its coal-fueled power capacity relative to the total electricity mix. The Turkish government recently announced plans to increase coal-fueled generating capacity from the current level of 17.3 GW to 30 GW by 2023 to further increase its independence from imported Russian natural gas.

Following an extensive due diligence initiative of the available CCP sources of supply, ZAG has established a long-term, secure supply position directly with the most reputable Turkish utilities. The combination of large-scale availability of CCPs for export, the proximity to end-use markets, and access to deep-water ports will assure customers in the Americas of a reliable, long-term supply solution.

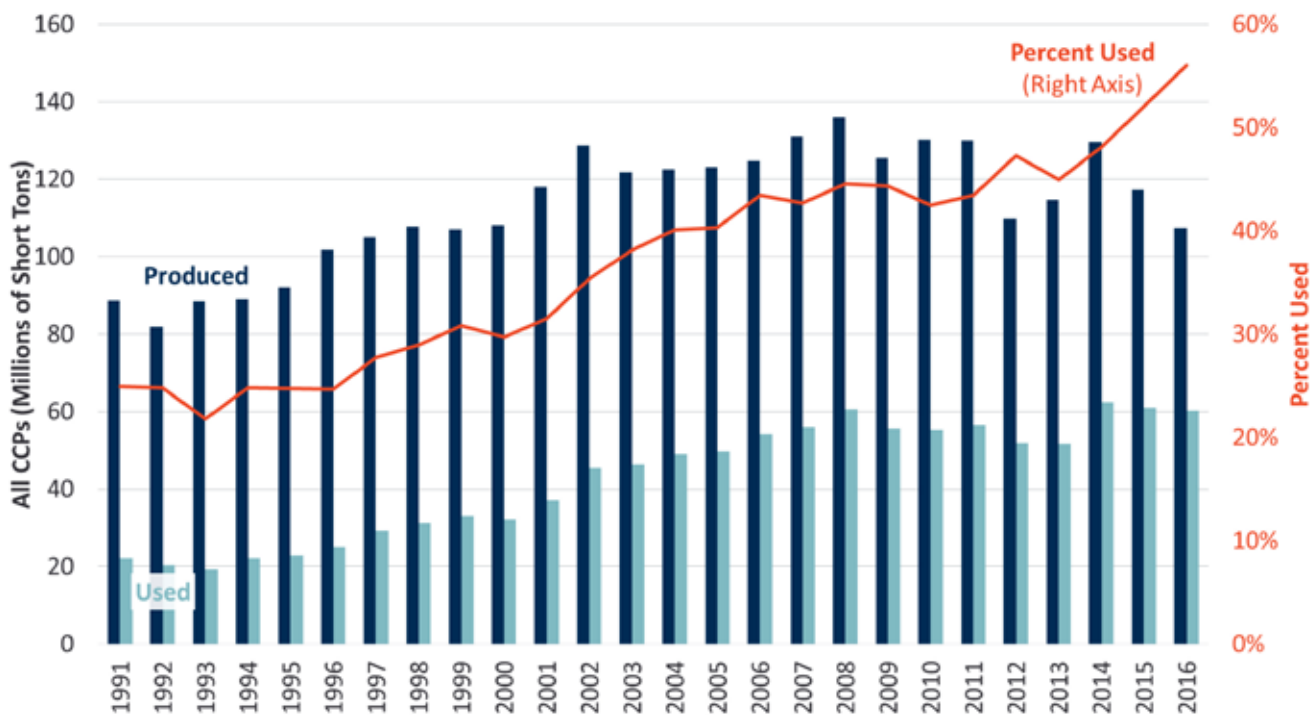
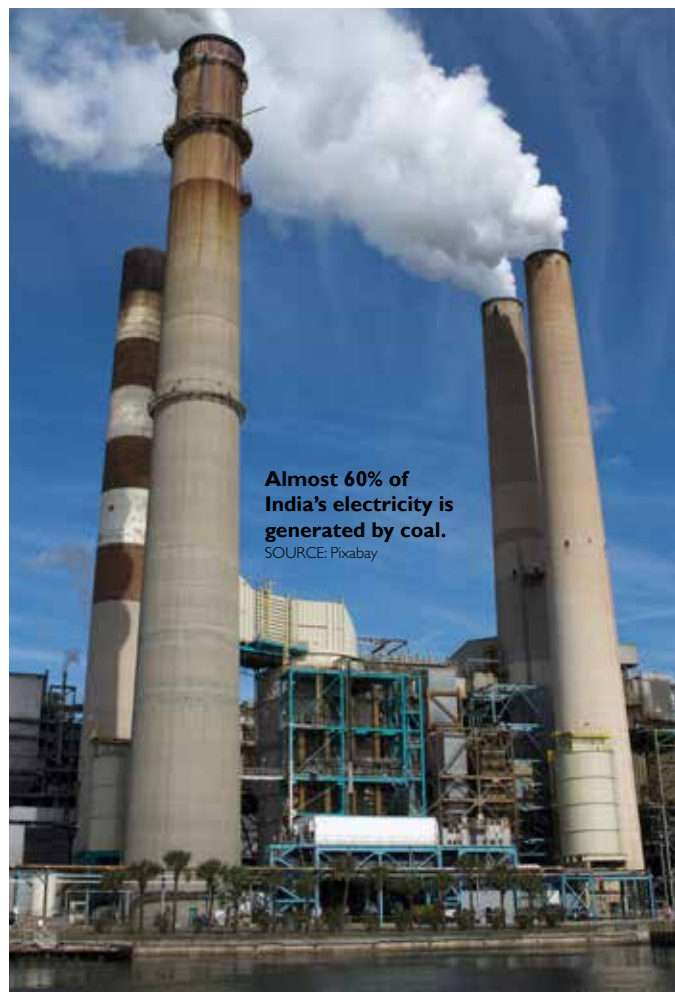


Figure 2. All CCPs production and use with percent.
SOURCE: ACAA



Portugal: In November 2016, the Portuguese environment minister confirmed that the country's power plants will eliminate coal-fueled generation by 2030. This was reaffirmed in 2017 when introducing the Roadmap to 2050 Carbon Neutrality. Similar to the Spanish approach to exporting CCPs, Portugal has exported CCPs on a "spot basis" from time to time, depending on the supply/demand balance within the domestic market.

Japan: Since the catastrophic accident at the Fukushima power plant, Japan has displaced nuclear electric-generating capacity with the rapid expansion of low-cost coal-fueled power generation. Now, coal-fueled power plants account for over 30% of Japan's total power mix, with plans to build additional coal-fueled capacity. However, in recent months there has been a spate of cancellations of coal-fueled power plant projects due to environmental pressures and the availability of imported liquefied natural gas.

While the extremely bureaucratic environmental regulatory hurdles to export CCPs from Japan will be onerous and difficult to overcome easily, it appears that Japan may serve as another potential export option for the future.

Why Are CCP Imports to the U.S. Needed?

According to the American Coal Ash Association's 2016 *Coal Combustion Product Production & Use Survey Report*, less than 60% of fly ash, less than 38% of bottom ash, and less than 58% of FGD gypsum produced were beneficially used (refer to Figure 2 above). If there are millions of tons of these materials not beneficially used, even with all the coal-fueled power plant closures, why are CCP imports needed? Like cement imports, CCP imports make up for domestic shortages and act as a safety valve to meet

domestic demand. The reasons vary by market type and region but the main issues are product quality and logistics, as well as the costs of remediation and recovery.

Because of the 1990 changes to the Clean Air Act, most coal-fueled power plants east of the Mississippi have scrubbers. With no economic advantage to using low-sulfur coal, most of these plants burn high-sulfur coal. High-sulfur coal produces high-iron coal ash. Most cement plants need more alumina than iron. Therefore, they prefer coal ash from low-sulfur coal, which is high in alumina and low in iron. In the EU even though most coal-fueled power plants have scrubbers, they are still required to burn low-sulfur coal producing high-alumina coal ash.

Most of the coal-fueled power units in the U.S. are decades old, and to comply with NO_x regulations they often produce fly ash with high loss on ignition (LOI). Because of the limited amounts of low-LOI fly ash, fly ash beneficiation and treatment have increased dramatically in the last few years to keep up with demand as coal-fueled plants close or are converted. Beneficiation costs are high, and the sources may not be near areas of high demand, thus posing logistical challenges. Because of the seasonal demand for concrete-quality fly ash, the supply often cannot meet the demand for fly ash during high-demand months.

When the scrubbers were installed, new wallboard plants were built next to or near the power plants to utilize this low-cost FGD gypsum. This resulted in the closure of many gypsum mines. Now many of these new wallboard plants built to use FGD gypsum are near power plants that have closed or are burning a lot less coal.

Finally, if domestic CCPs are available with reasonable freight cost, imports cannot compete. Imports will only be competitive on the coastal areas because truck and rail costs to and from the coasts are very expensive. In addition, most coal-producing areas are inland in the Appalachian, Illinois, and Powder River basins. Coal can be moved more economically on the Ohio and Mississippi Rivers, and Powder River Basin coal is moved by rail. Therefore, coal will compete better with natural gas in the interior of the U.S.

Most of the gypsum mines in the U.S. are also in the interior of the country. The demand for CCPs for ready-mix concrete and gypsum are population based, and most of the U.S. population is closer to the coasts.

Important Considerations for Importing CCPs to the Americas

CCP source due diligence and pre-qualification steps:

- ZAG's global team of technically qualified personnel visit all prospective sourcing locations to evaluate and vet each site and products prior to considering it for its product portfolio.
- ZAG's logistics team is responsible for assessing the full range of factors impacting both the cost and viability of exporting CCPs from a particular source to ZAG's customers. Factors such as shipment sizes, loading and discharge rates, berth draft levels, SHINC versus SHEX ports, and berth access can

all be major influences in comparing the commercial value of one source relative to another.

- Following the technical/sourcing reliability and logistics assessments for each source, ZAG's local country managers and their team negotiate long-term, secure supply agreements that offer customers the assurance of a consistent and reliable supply solution.

Incorporating CCP source into existing ZAG product portfolio:

In addition to leveraging ZAG's significant global shipping volume to secure the most cost-effective freight rates for customers, ZAG's in-house chartering group also focuses on efficiency improvements whenever incorporating new sources of CCPs into ZAG's total logistics planning.

Addressing load port/discharge port storage limitations: As most offshore utilities originally sized their dry fly ash silos to meet the just-in-time demand requirements of the local concrete market, it is rare for a utility to have dry storage silo capacity in excess of 20,000-25,000 MT. This dry storage limitation can often create a cost premium for exporting dry ash by ocean vessel, as the most common vessel classes to the U.S. (Handymax and Supramax) typically transport 40,000-55,000 MT cargo sizes. To offset this premium, ZAG will include other CCPs (conditioned fly ash, bottom ash, FGD) from the utility or other products in the same cargo.

ZAG's multiple supply options for CCPs: Unlike "spot" traders, ZAG's long-term supply strategy for CCPs includes an extensive portfolio of CCP sourcing locations in order to assure customers that they will not incur interruptions in supply related to continued reductions in coal-fueled power generation at a given utility.

Conclusions

- CCP production in the U.S. and Europe will continue to decrease.
- CCP production will continue to increase in Asia, Turkey, and India.
- CCP imports serve as a safety valve to meet high demand in coastal areas with insufficient supply.
- Effectively importing CCPs requires a comprehensive, long-term commitment that includes establishing direct relationships with high-quality, reliable sources of supply, incorporating a quality control plan with direct oversight to ensure product consistency for customers, and the internal logistics expertise and flexibility to manage the complex logistic components from the point-of-load port to customers. ♦

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Rick Haverland is the Technical Director for ZAG International. He has a Bachelor of Science in civil engineering and a Master's in sanitary engineering. For over 30 years Rick has developed the beneficial use of gypsum and coal ash from power plants and industrial boilers.

South African Fly Ash Used to Help Build the Continent's Longest Suspension Bridge

By Mark Hunter

Mozambique sits astride the Indian Ocean and shares a southern border with South Africa. This developing country is now nearing completion of a major infrastructure project—the construction of a bridge linking the capital, Maputo, with the city of Katembe—that is expected to benefit the region by reducing travel time between the two countries and boosting economic opportunities.



The project is one of the major capital investment initiatives undertaken by the Government of Mozambique, which appointed the China Road and Bridge Corporation as the main contractor and GAUFF Engineering as consultant. The bridge, built over the Bay of Maputo, has an open span of some 680 meters and a clearance height of 60 meters to accommodate the bay's very active shipping lane. Providing a connecting route that will trim road-based transportation times to South Africa—from which Mozambique imports many of its staples—by at least three hours, the bridge is expected to open new investment options in the region.

With sustainability a critical consideration in the bridge's construction, balancing social, environmental, and economic factors required innovative thinking. This led to the choice of substituting at least 35% of the cement in the concrete with South African fly ash. The reduced emissions associated with the use of the fly ash at 2 kg CO₂ e/ton—compared to cement at 840 kg CO₂ e/ton—yielded substantial environmental benefits.

Construction

The bridge's main cables are affixed to two massive “anchor” blocks on the north and south side of the bay situated 260 meters and 284 meters from the main pylons, respectively. Two circular shafts 50 meters deep with a diameter of 50 meters each have been constructed to house the concrete and sand-filled anchor blocks, which support the entire main span of the bridge. For perspective, the south bank anchor block weighs 177,000 tons. This is a concrete block the size of a football field 15 meters high.

Bridge builders employed three different methods of construction. The north approach uses the balanced cantilever method, one of the most technically challenging bridge construction technologies, which is further complicated by the fact that it is on a curve. The main span of the suspension bridge, the south approach, consists of post-tensioned T-beams of 30 and 45 meters, respectively. The north bank pylon is 135 meters high, and the south bank pylon stands at 136 meters.

- The north approach balanced cantilever bridge consists of post-tensioned reinforced concrete box girders and will be 1097 meters in length, with the largest span being 119 meters.
- The southern approach precast T-beam bridge is 1234 meters long. A total of 283 concrete piles with diameters

The Maputo-Katembe bridge will reduce travel time and boost trade opportunities in Southeast Africa.

SOURCE: South African Coal Ash Association

- of between 1.5 and 2 meters, and 55 meters in length, were constructed on the south bank; 138 piles line the north bank.
- The two pylon pile caps are supported by 24 piles with a diameter of 2.2 meters each sunk to an average depth of 110 meters.

The main cable is composed of 91 galvanized high-strength 5-millimeter steel wires, resulting in a total cable diameter of half a meter, two of which will run parallel over the pylons from anchor to anchor. The total length of the wires is a staggering 10,899 kilometers.

Concrete Mixture

Two computerized batching plants are dedicated to the construction of the Maputo Bridge. One plant is situated in Maputo and the other is in Katembe. Both plants are within 2 kilometers of the site. The capacity of each plant is 120 m³ per hour.

Fly ash supplied by Ulula Ash is transported from South Africa to Cemento Maputo in Matola approximately 15 kilometers away and is stored in large silos at the respective batch plants. Aggregates from four suppliers are stockpiled on site to ensure the ability to produce concrete 24 hours a day, 7 days a week. The contractor has 12 approved mixture designs.

The siliceous fly ash used complies with the SANS specification and provides the following benefits:

- Increased later-age strength—for example, at 90 days

- Reduced rate of chloride diffusion through the concrete
- Prevention or retardation of alkali-silica reaction
- Reduction in rate of heat generation by up to 20%
- Reduced shrinkage due to lower water demand
- Significant reduction in the risk of thermal cracking
- Improved sulphate resistance.

Physical testing is being performed in the on-site laboratory to confirm the results received.

High workability of the concrete was one of the main design parameters. Constructing piles 110 meters deep, and pumping the concrete to a height of 140 meters, meant that a very fluid concrete was required.

Project Participants

- The Government of Mozambique, represented by Empresa de Desenvolvimento de Maputo Sul.
- GAUFF GmbH & Co. Engineering KG, Nuremberg, Germany/Maputo, Mozambique.
- China Road and Bridge Corporation, Beijing, China. ♦

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Fly Ash from Thermal Power Plants in India: The Challenge of 100% Utilization

By Dr. Anjan K. Chatterjee

Generation of electricity in India is and will remain predominantly dependent on the use of high-ash coal as fuel. The installed capacity of electricity generation with coal as fuel at the end of March 2017 was 192 GW, constituting approximately 59% of the total electricity-generating capacity in the country.

Based on annual reports available from the Central Electricity Authority, the monitoring authority of the government of India, it appears that the use of coal ash during the period from April 2016 to March 2017 was in the range of 63% of the generated quantity. Cumulatively, the unused stock of coal ash is increasing substantially every year, and the management of coal ash from thermal power plants has been a matter of great concern in the country, primarily for two reasons: the requirement of large land area for disposal, and the hazard of causing air and water pollution.

The targets set periodically to reach 100% coal ash use in a phased manner have so far remained elusive. Ash use has traditionally been in the construction sector, with the production of blended cement consuming more than 42%. The persistent gap between the generation and use of ash, and the visible limits of significantly increasing its use in traditional sectors, have compelled academia and industry to study the material's characteristics and its application properties more scientifically and comprehensively. One of the focus areas is to search for methods to make fly ash, the major portion of coal ash, more reactive and consistent in quality. This paper attempts to highlight some of these investigations of Indian fly ash.

Introduction

Based on feedback received from 155 coal-based thermal power station operators in India for the period of April 2016–March 2017, the country-wide status of coal ash generation and use has been summarized by the Central Electricity Authority, the federal agency coordinating the operation and growth of the power industry, as follows:

- Installed capacity (MW): 157,377
- Coal consumed (MT): 509.46
- Average ash content in coal (%): 33.32
- Total coal ash generation (MT): 169.25
- Total coal ash use (MT): 107.01
- Coal ash use as percentage of generation: 63.26%

While these statistics correspond to an electricity-generating capacity of about 157 GW, the installed capacity of coal-based thermal power stations at the end of March 2017, as stated earlier, was 192 GW. It is, therefore, quite obvious from a simple extrapolation of the same operational parameters that the total coal ash generation must have already exceeded 206 MT. Correspondingly, it is estimated that the fly ash availability, being approximately 20% of the total ash during the same period, must have been about 165 MT. Moreover, it is rational to assume that the entire use of 107 MT of coal ash during the period of April 2016–March 2017 must have been for the fly ash component, as the use of bottom ash or pond ash, as of now, is rather insignificant in India. Hence, it is implied that during the aforementioned 12-month period, the quantity of coal ash that has been added to the vastly accumulating ash ponds was about 58 MT. The current modes of fly ash use are shown in Figure 1.

From Figure 1, it is also evident that the current modes of fly ash use are all in the traditional areas, and the manufacture of blended portland cement is the major type of application. How the application scenario would emerge in the future to bridge the gap between generation and use of coal ash is the focus of this article.

Tentative Future Trends

Taking into account the current specific consumption of coal per megawatt of electricity and the increasing trend of average ash content in coal rising up to, say, 40% in the near future, an additional 116 GW of installed capacity of coal-based thermal power by 2022—if ultimately realized as planned—may result in the generation of more than 400 MT of coal ash annually. If current modes and trends of ash use continue in the future, there would be an appalling accumulation of unused coal ash causing environmental pollution problems. Technologically, the bridging of the gap cannot be attempted by developing niche application strategies. Success lies in achieving newer technological approaches for bulk use and in maximizing its use in cement, concrete, mine filling, and agriculture. The feasibility of such expansion in ash application sectors depends on the characteristics of Indian fly ash and the capability of the research community to manipulate its properties.

Characteristics of Indian Fly Ash

Characterization of coal ash in general, and fly ash in particular, is being conducted or observed broadly from three angles:

- Determination of intrinsic physical properties, chemical composition, and phase characteristics of the material.
- Detecting the special attributes that are essential for specific applications such as road sub-base, embankment, cement, concrete, mine filling, masonry products, and in agriculture.
- Determining the amenability of fly ash for further processing for new and advanced fields of application.

The salient characteristics of Indian fly ash are briefly described in the following.

Bulk composition: For geotechnical applications, samples of fly ash, pond ash, and bottom ash have often been compared with soil. Similarities and overlapping of the compositions have been noticed. Pond and bottom ash sometimes have higher concentration of silica; the alumina percentage in the bottom ash appears to be lower than the other two varieties. The presence of soluble solids significantly differs: 400 to 17,500 ppm in fly ash, 800 to 3600 ppm in pond ash, and 1400 to 4000 ppm in bottom ash. All the coal ash samples tested were found to be nearly alkaline, and in relative terms, fly ash showed higher pH than pond ash and bottom ash.

With respect to fly ash, the variety predominantly available in India is of the Class F type and is characterized by relatively higher concentrations of silica (~60%) and lower contents of ferric oxide (~4 to 5%) and calcium oxide (~2 to 3%) than Class C variety. The alumina content in both varieties is more or less similar, in the range of 25 to 28%. The chemical composition of Class F type implies higher fusion temperature for the material and hence a lower chance of glass formation. The trace and heavy metals (Se, Cr, Pb, Co, Ni, Cd, As, and Hg, as measured in several samples) as well as radionuclides (^{226}Ra , ^{228}Ac , and ^{40}K) in fly ash samples are negligible and comparable with most of the field soils. There is an overall comfort level in India that radioactivity of fly ash is not a deterrent to its use, as the source coal in general is very low in radionuclides.

Phase composition: It has been observed widely that the Indian low-lime Class F fly ash is more crystalline than those obtainable in other countries. The glass content in mixed fly ash samples is close to 30%, while the samples drawn from the second and third chambers of ESPs in selected power plants show higher glass content, in the range of 45 to 60%. Generally, the ratio of network formers ($\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$) to network modifiers ($\text{Na}_2\text{O} + \text{K}_2\text{O} + \text{CaO} + \text{MgO}$) in Indian fly ash is too high and unbalanced to form high

proportions of glass. As an example, the crystalline character of the Indian fly ash samples has been compared with that of a Canadian fly ash sample in Figure 2. The hump at 22 to 24 degrees two-theta values in the XRD patterns of the fly ash samples, given in Figure 2, gives a fair comparison of the glass contents in them.

Studies on Improving the Properties and Characteristics of Fly Ash

From the previous sections of this discourse, it is evident that coal ash, and more particularly fly ash, has been quite effective as a resource material in certain fields of application, and yet there is a big gap between generation and use. Hence, studies are continuing in the country to improve the properties and characteristics of fly ash in particular. Some of these studies are highlighted as follows.

Nodulation and Sintering of Fly Ash

One of the problems in using fly ash in bulk is its dust pollution during transportation and handling, for which special arrangements have to be made. An alternative technological approach is the option of producing sintered fly ash nodules. In this process, a suitable forming machine is used to convert the fly ash into

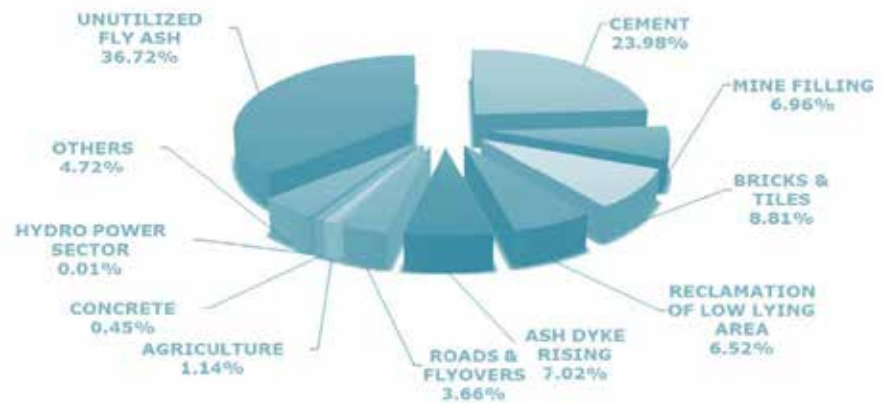


Figure 1. Fly ash use in India from April 2016 to March 2017

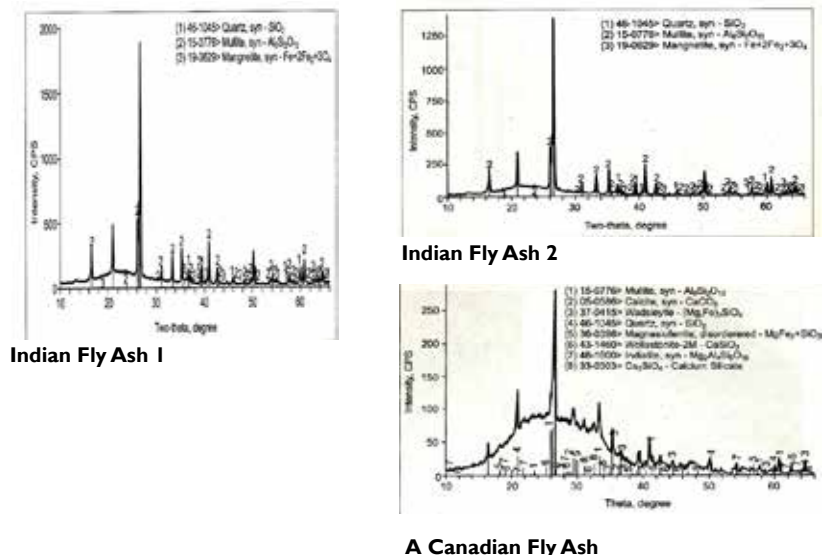


Figure 2. Comparison of glass content in Indian and foreign fly ash samples

nodules, granules, or briquettes by preparing a feed mix with 4 to 7% plastic clay as a binder. Nodules are of 6 to 10 mm size, and the sintering temperature is 1100 to 1150° C. Shaft kilns, rotary kilns, or stationary or moving grate furnaces can be used for this purpose. The process can use up the residual carbon present in the fly ash, supplemented with additional solid fuel as required. The sintered nodules offer the advantages of non-polluting transportation, handling, and storage of fly ash with somewhat improved properties due to the removal of carbon particles on burning. Such sintered nodules can also be used as lightweight aggregates in the building industry.

Prospects of Enhancing Glass Content

The basic chemistry shows that the glass content in fly ash is a critical requirement for its reactivity, and at the same time, the Indian fly ashes, as shown earlier, are predominantly crystalline. To find out a solution to this problem, this author attempted to re-vitrify the low-lime siliceous fly ashes with the help of sodium carbonate and ferrous oxide as fluxes. The fly ash samples were mixed with the fluxes individually up to 5% and fired at different temperatures up to 1525° C. The X-ray diffraction patterns of the samples fired at 1525° C are shown in Figures 3(a) and 3(b). While there were no phase changes at lower temperatures, at 1525° C with sodium carbonate as the flux, the quartz peaks disappeared but the mullite peaks were unchanged. But with ferrous oxide as the flux, the quartz phase converted into cristobalite with no change in the mullite phase. The Chapelle test was conducted with the fired and unfired fly ash samples, and it was observed that the fired sample with dissolved quartz did not show any visible improvement in the fly ash reactivity. It seemed therefore that, apart from the quartz phase, the dissolution of the mullite phase was necessary for the re-vitrifying process, which required a very high temperature and made the process unworkable. As an alternative, the feasibility of the re-melting process by making a clinker of alkali aluminate chemistry is still being examined.

Chemical Activation

The chemical activation of fly ash usually refers to the processes of alkali and/or sulfate activation of the material. The alkali activation involves dissolution of the glassy phase in an increased alkaline environment, thereby accelerating the pozzolanic reaction. It is obvious that for glass-deficient fly ashes, this process of activation may not be very effective. On the other hand, the sulfate action involves its ability to initiate reactions with the aluminous phases, thereby generating the strength-imparting hydrate phases in cement hydration. This also has a relation to the order of crystalline nature of the alumina-bearing phases and their dissolution kinetics. Geopolymer cements and concretes have been developed on the basis of the reactions occurring between slag or fly ash and alkaline fluids, resulting in three-dimensional polymeric chain and ring structures consisting of Si-O-Al-O bonds. Here also the glass chemistry and its dissolution characteristics would play an important role. The crystalline nature of the Indian fly ashes is not expected to be very conducive to such reactions under normal circumstances. Nevertheless, the alkali reactivity of some Indian fly ashes has been studied. As an illustration, a study conducted with five siliceous fly ash samples collected from five different sources

having silica and alumina contents ranging from 55.83% to 61.65% and 20.67% to 30.06%, respectively, is briefly reported here. The XRD patterns showed very shallow humps at 24 to 26 degrees two-theta, indicating the glass phase to be quite low, tentatively in the range of about 20% or so.

The activation trials were carried out in three modes:

- i. The first set of experiments was conducted with 5% binders prepared individually from the analytical grade sodium hydroxide, potassium hydroxide, calcium hydroxide, and their carbonate and sulfate forms dissolved in 200 mL of mixing water. The casting mixtures were prepared in a mechanical mixer with 500 g of each of the fly ash samples and 1500 g of standard graded sand. The mixes were cast in 50 mm cube molds and cured at 27 and 50° C until the age of breaking. In this set of experiments, the cubes could not be taken out from the molds, as no handling strength was gained even at elevated temperature.
- ii. In another set of experiments, two fly ash samples differing in their mullite contents from the five mentioned earlier were selectively taken and mixed with 1N sodium hydroxide solution and nodulized. The nodules were heat treated at 400° C for approximately 20 minutes. After cooling to room temperature, the hardened nodules were crushed and the gel-like substance was mixed with standard graded sand at a ratio of 1:3. The mixtures were cast in cube molds and cured at 50° C until the age of crushing. In this set of experiments, unlike the previous one, activation was triggered and the fly ash samples showed 1-day strengths of 4.8 and 6.7 MPa, and 3-day strengths of 7.2 and 9.7 MPa, respectively.
- iii. The third set of experiments was carried out with silicates of sodium, potassium, and calcium, respectively, as binders at a dosage of 5% of the fly ash mass. While the sodium silicate was of the composition $\text{Na}_2\text{SiO}_3 \cdot 9\text{H}_2\text{O}$, the potassium silicate was pure K_2SO_4 powder and the calcium silicate was in the metasilicate form. The rest of the experimental procedure, including high-temperature curing, was unchanged. The results obtained are shown in Figure 4. In continuation of this set of experiments, the molarity of sodium silicate was altered with the addition of sodium hydroxide to the basic sodium silicate, and the effective binder dosage could be reduced for a similar level of strength gain.

The relationship of molarity of the alkaline fluid, fluid-to-fly ash ratio, and compressive strength development is shown illustratively from another set of experiments in Table 1.

It may also be relevant to mention here that in this author's laboratory, some exploratory work had been carried out to ascertain the relationship between compressive and flexural strengths of alkali-activated siliceous fly ashes, without any sand addition, with the help of prism mold casting tests. With alkali binder dosage of 2.5% $\text{Na}_2\text{SiO}_3 \cdot 9\text{H}_2\text{O}$ + 2.5% NaOH, the strength properties obtained were as shown in Table 2.

It is interesting to note that with alkali activation, the fly ash by itself developed good strength, and more interestingly the flexural strength was 30 to 40% of the compressive strength. In the case of crystalline fly ash, the dissolved alumina seems to react

with the silicate supplied by the activating solution, and this leads to the formation of alumina-silicate diatomers. This may be the reason why the use of sodium silicate solution generally has a better activating property than sodium hydroxide. Further, the supplementation of sodium hydroxide to sodium silicate apparently helped in the growth of N-A-S-H gels.

Ultrafine Grinding for Mechanical Activation

For mechanical activation, various milling options are being explored in laboratories and pilot plants in India. The main objective in such experimental studies has been to ascertain if elastic, plastic, and shear deformations could be introduced into the fly ash particles, leading to their fracture and transformation to an amorphous state. Mechanical milling is known to be the most productive method of producing large quantities of nanocrystalline powders of different types of materials such as metals, alloys, intermetallics, ceramics, and composites. Milling and mechanical alloying are carried out using high-energy planetary, ball, and vibration mills, where the mean size of the powders produced may vary from 200 to 5-10 nm.

It has been reported that by milling the beta form of iron boride in a ball mill, it is possible to produce its alpha form with a mean crystallite size of about 8 nm. Mechanical treatment of barium titanate in a planetary mill can produce a nanocrystalline powder with a mean particle size of 5 to 25 nm. Mechanical alloying of the powders of borides, carbides, silicides, oxides, and sulfides of transition metals has been carried out by the “explosive” method in vibration mills. The powders of transition metal nitrides with a particle size of several nanometers are synthesized by milling in vibromills in nitrogen atmosphere. Mechano-chemical synthesis in ball mills of nanocrystalline carbides of titanium, zirconium, vanadium, and niobium from powder mixtures of metal and carbon has also been reported. Ball milling can be used to make a variety of new carbon types, including carbon nanotubes.

However, the experience of mechanical milling of the Indian fly ash is quite

different. The typical results are shown in Table 3. Based on a large number of experiments of fly ash grinding conducted by the author at laboratory scale,

the comparative results of ball milling and vibro-milling in dry mode and attrition milling in wet mode can be summarized as shown in Table 4.

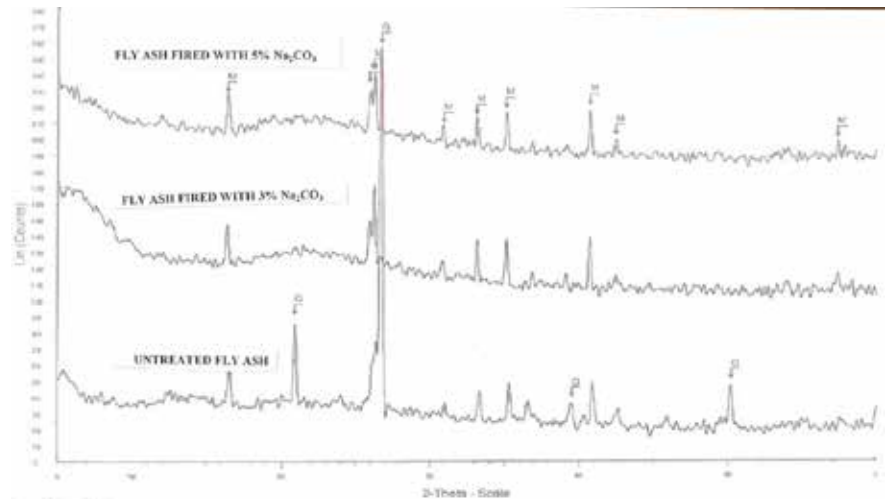


Figure 3(a). XRD patterns of siliceous fly ash treated with sodium carbonate vis-à-vis untreated sample. Note: M is mullite and Q is quartz

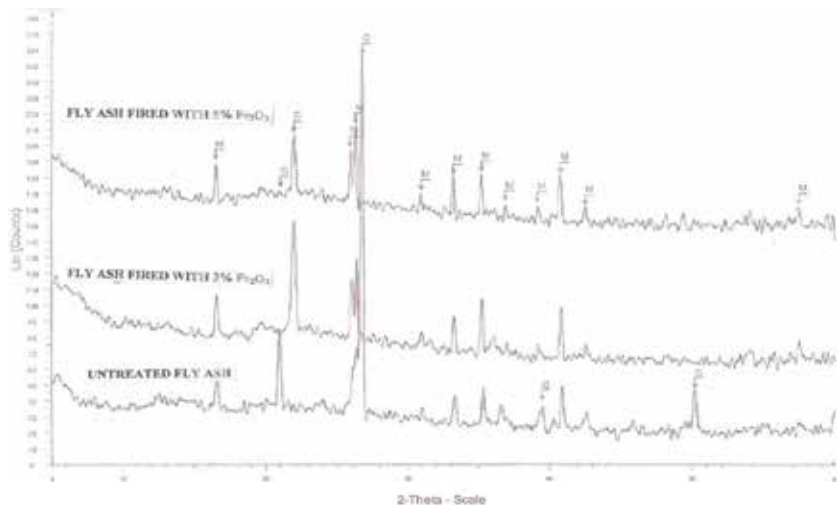


Figure 3(b). XRD patterns of siliceous fly ash treated with ferrous oxide vis-à-vis untreated sample. Note: M is mullite, Q is quartz, and C is cristobalite

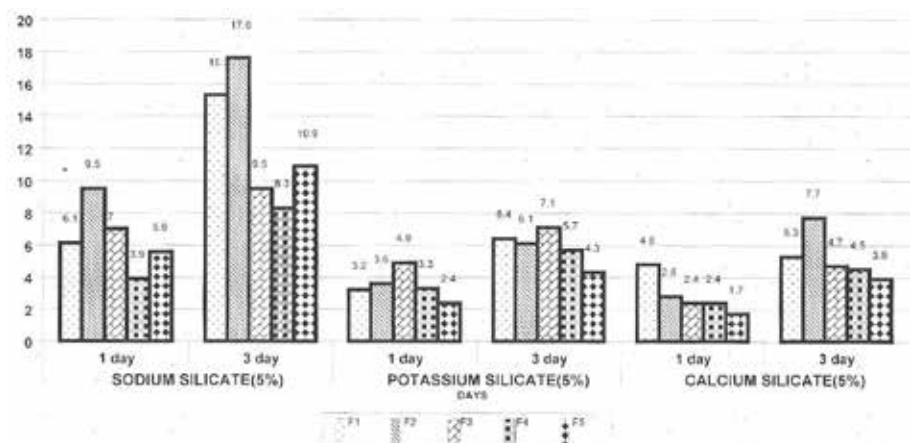


Figure 4. Compressive strengths of fly ash-sand mortars with alkali silicate binders

Table 1. Relationship of molarity of alkaline binder to compressive strength values of activated siliceous 1:1 mortar, in MPa

Fluid/Fly ash ratio	Fly ash/fluid ratio	4 M Binder		8 M Binder		10 M Binder	
		3-d	7-d	3-d	7-d	3-d	7-d
0.30	3.33	4.8	6.0	16.0	20.0	24.0	26.0
0.40	2.50	3.0	4.0	11.8	14.5	16.0	19.0
0.50	2.00	1.5	2.4	8.0	11.0	12.0	14.0
0.60	1.67	0	0	6.0	8.6	10.0	11.0

Table 2. Strength properties of siliceous fly ash with 5% alkali fluid of enhanced molarity

Age	Compressive strength, MPa	Flexural strength, MPa
3-day	14.5	5.5
7-day	34.0	10.8

Table 3. Results of extended ball milling of siliceous fly ash

Grinding time, h	Blaine's surface, m ² /kg	Density, g/cm ³	Lime reactivity, MPa
0	300	2.10	5.8
1	490	2.30	7.0
2	550	2.35	—
3	630	2.39	—
4	710	2.42	9.5
5	780	2.48	—

From Table 4, it is evident that in the case of dry milling, the vibratory mills displayed significantly lower milling time and better product characteristics. But the attrition mill in wet mode showed even better performance. However, the average particle size of fly ash ground in different milling systems ranged from 3.0 to 9.0 μm , and the enhancement of fly ash reactivity was, for all practical purposes, proportional to the levels of fineness achieved. No discontinuity or sharp change in the product reactivity was observed. The XRD patterns and scanning electron micrographs did not show any noticeable difference. The XRD patterns of differently milled fly ashes and that of a silica gel are compared in Figure 5 and their pozzolanic behavior is compared in Table 5.

All these observations, *prima facie*, did not reveal any quantum jump in reactivity of the Indian fly ash by milling, as expected from what is understood by “mechanical activation.” Some improvement in reactivity was due to the proportional increase in the specific surface area of fly ash due to milling. In vibro-milling and attrition milling, there is some potential to reduce the milling time and consequently the energy consumption, and so the scale-up possibilities of these systems were examined.

Scale-up possibilities of the new milling systems: Two specific attempts made in the recent past are briefly mentioned here. A pilot vibratory mill of 1.5 tph rated throughput with twin tubes of 600 mm diameter and 3500 mm length had been installed

in the premises of one of the cement plants in India. The rated mill drive of 90 kW was provided with 62% volumetric filling of cylpebs of 30 x 30, 25 x 25, and 20 x 20 mm sizes. For this installation, the problems encountered were the non-achievement of the rated throughput, desired reduction ratio, and the expected specific power consumption.

Another endeavor has been with a tower mill as a variant of the attrition mill but in dry mode, keeping in view the fact that tower mills or vertimills of throughputs of up to 100 tph were in industrial operations but in wet mode. The pilot-scale trial runs with the Indian fly ashes having a feed particle size in the range of 1 to 100 μm did not yield the d_{50} value of even 10 μm with specific power consumption of up to 110 kWt/t of fly ash. Use of coarse media (6 mm), low tip velocity of the stirrer (3 m/s), and dry mode were considered responsible for not achieving the expected performance. Other milling systems, such as the stirred mills in general and more particularly the horizontal IsaMill type, merit some attention, and the “power intensity” values of different mills need to be compared. At the same time, the feasibility of dry grinding will have to be kept in view.

Threshold Fineness of Fly Ash for Mechano-Chemical Activation

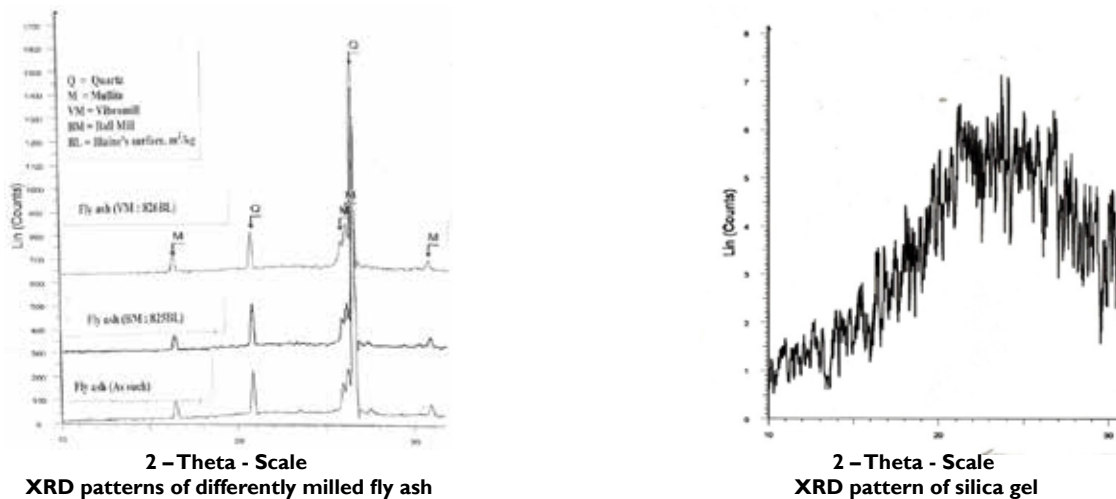
With the known technologies of fine grinding and high-efficiency cyclone classification, the particle size of the Indian

Table 4. Laboratory-scale grinding of fly ash in different milling systems

Mill system and mode of milling	Milling time, min	Factor of increase in Blaine surface	Reduction ratio of median particle size	Factor of increase in lime reactivity
Ball mill (dry)	300 – 360	3.0 – 3.5	3.0 – 3.5	2.0 – 3.0
Vibratory mill (dry)	50 – 60	3.5 – 3.8	5.0 – 6.0	2.5 – 3.0
Attrition mill (wet)	30 – 40	3.5 – 4.0	8 – 10	2.5 – 3.0

Table 5. Residual calcium hydroxide in cement and mineral admixture blends after 3 days of hydration, as determined by TG-DSC at 1000° C

Serial no.	Blend composition	Ca(OH) ₂ %
1	OPC + 25% as-received fly ash	10.90
2	OPC + 25% ball-milled ground fly ash	16.60
3	OPC + 25% vibratory-milled fly ash	7.73
4	OPC + 25% silica gel	Nil

**Figure 5. Comparison of XRD patterns of ultrafine ground fly ash and silica gel**

crystalline fly ashes remains above 1 and below 10 μm in general, which is much coarser than even the field designated as “submicrocrystalline” by Gusev and Rempel in 2008 having mean grain size in the range of 300 to 40 nm. In materials science, it is generally observed that a decrease in the size of the crystals below some threshold value results in a large change of properties. These effects occur, as it is believed today in nanoscience, when the mean size of crystalline grains does not exceed 100 nm. Whether this threshold value holds for fly ashes in general and the highly crystalline fly ash in particular is an issue to be resolved. However, the performance of silica fume having mean particle size of 100 nm in general (Table 6) has given an indication that the quantum jump in the properties of fly ashes cannot be expected as long as the mean particle size remains above 1 μm , which has been seen so far as the size reduction limit of the known fine grinding and classification technologies that have the potential of up-scaling.

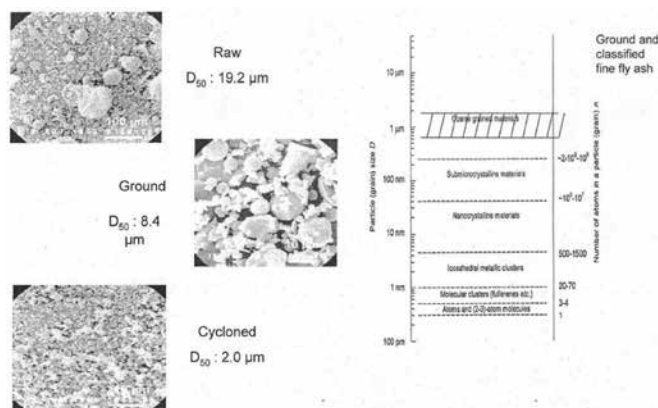
In search of the threshold particle size of fly ash to obtain a large change in properties, it may be worthwhile to compare with

certain other mineral admixtures and fillers used in the cement and concrete industry in terms of their particle characteristics and reactivity. As already mentioned, silica fume is an effective mineral admixture. Depending on the source, the silica content may vary from 94 to 98% in the case of silicon metal and between 86 and 90% in the case of alloys. The average particle size is about 100 to 150 nm and the BET surface is 15 to 25 m^2/g . The comparative effect of the use of silica fume has already been shown in Table 6.

There are other silica colloid suspensions available in the market. One such admixture contains silica colloid particles to the extent of 30 to 60% by weight of the solution. The specific surface area of the particles is in the range of 50 to 200 m^2/g and the mean size of the particles ranges from 5 to 200 nm. It is reported that 4% of such a silica colloid consumes about 60% more calcium hydroxide than 4% silica fume in the same time span of 7 days. The higher reactivity of the silica colloid suspension is on account of its nano-level particle size and its purity.

Table 6. Performance comparison of classified fine fly ash and silica fume as concrete admixture

Serial no.	Composition/properties	Control	Fly ash	Silica fume
1	d_{50} , μm	—	3.0	<0.1
2	Addition, %	0	10.0	10.0
3	w/c ratio	0.40	0.40	0.40
4	Cement, kg/m^3	400	357	356
5	Slump, mm	100	80	80
6	Compressive strength, MPa			
	7-day	56.2	54.5	71.0
	28-day	67.9	68.7	80.7
7	Rapid chloride permeability, coulomb			
	7-day	2922	1083	429
	28-day	2340	758	297

**Figure 6. Diagram showing achieved particle size of processed fly ash in scale of fine materials**

Another important concrete admixture is metakaolin containing 51 to 55% silica and 40 to 45% alumina. The BET surface area is in the range of 14 to 22 m^2/g with particle sizes of 60 to 90% under 2 μm and less than 15% above 5 μm . This type of admixture shows a pozzolanic reactivity of 840 mg CaO g^{-1} of metakaolin as determined by the Chapelle test. Because the fly ash has substantially lower alumina than metakaolin, and silica is present in quartz and mullite form, it needs to be ground to sub-micron particle size to display comparable pozzolanic capability. Finally, it may be relevant to compare the behavior of the finely ground limestone filler in cement. It is generally co-ground with clinker and, because of its softness, becomes finer than the clinker. For an overall Blaine's surface area of 420 m^2/kg , the particle size of about 50% of the filler is often below 700 nm as compared to 3 μm of the clinker component. Because of the fineness, it accelerates the hydration of the alite and aluminate phases. Chemically, it reacts with the aluminate phase, producing a hydrated carboaluminate phase, thus competing with gypsum.

From the aforementioned examples, one may observe that the submicrocrystalline materials are likely to behave quite differently from materials coarser than 300 nm, as depicted in Figure 6. Hence, it is certainly worth looking at the feasibility of bringing down the mean particle size of the crystalline fly ashes at least to

the "submicrocrystalline" range and observing the corresponding improvement in reactivity by any of the standard procedures.

Conclusions

Based on the observations herein, an exercise is being contemplated to optimize the top size of the ultrafine Indian fly ash particles along with their size distribution pattern so as to realize the tangible benefits of mechano-chemical activation in its proper sense. The scope of this optimization exercise is to answer the following questions:

- Is there a sharp and distinctive boundary between the bulk and the submicrocrystalline states for crystalline fly ash?
- Is there any critical grain size below which the characteristic properties of submicrocrystalline, or more particularly of nanocrystalline, fly ash become noticeable?

It will have to be determined whether the transition from the bulk to the nanocrystalline state is the phase transformation of the first order for the fly ashes under consideration from the thermodynamic point of view. In this exercise, the development of an appropriate conversion technology for the Indian fly ashes from the bulk to the nanocrystalline state will turn out to be the most important step.





Because of the characteristics of Indian Class F fly ash and the urgency of filling the gap between its current generation and use, it is imperative to explore the newer bulk application options more innovatively. Expediency in research and innovation is the only savior for India to tackle the glaring problem of environmental pollution due to massive generation of fly ash in the near and not-too-distant future. ♦

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Environmental Assessment of Coal Fly Ash Usage in Agriculture and Infrastructure Projects in Israel

By Dr. Nadya Teutsch

This paper is dedicated to Omri Lulav, who was the driving force behind coal ash utilization in Israel for over two decades and passed away suddenly in July 2018. An appreciation of his life and work will be published in the next issue of ASH at Work.

Coal ash production as a by-product of electricity generation in Israel commenced with the installation of the country's first coal-fueled power plant (Orot Rabin in Hadera in 1982) and grew with the establishment of a second plant (Rutenberg in Ashkelon in 1990). Coal ash production reached peak levels in 2012, with over 1.4 million metric tons generated (1.26 million and 183,000 metric tons of fly ash and bottom ash, respectively). Since then, with Israel's use of natural gas as an energy source for electricity production, coal ash production has decreased significantly (724,000 and 80,000 tons of fly ash and bottom ash, respectively, in 2017).

The Israeli National Coal Ash Board (NCAB), a governmental agency, was established in 1993 to coordinate solutions at a national level to solve the problem of ash accumulation at the power plants. The NCAB aims to maximize use of coal combustion products by advancing their safe use as a resource having economic value, as is done in other countries worldwide. Currently, the use of coal fly ash in Israel spans a number of application fields, including infrastructure, construction, industry, and agriculture (refer to Figure 1).

In the various applications in which it is used, fly ash comes into contact with, or is blended with, other substances that influence its characteristics. From previous studies conducted in Israel and worldwide, it is known that trace-element leaching depends strongly on the pH level, the extent of liquid contact, and the physical-chemical properties of the resultant product. Israeli

fly ash research is attempting to understand the fly ash "as-is," as well as in mixtures, to estimate the likelihood of release of constituents of potential concern under varied environmental conditions.

Incorporating LEAF in Israeli Fly Ash Characterization and Research

Over 20 years of collaboration between research teams in the United States and Europe in the fields of leaching, environmental assessment, and test standardization resulted in the joint-scheme Leaching Environmental Assessment Framework (LEAF). The framework recommends a collection of four leaching tests that follow the tiered approach of leach testing as published in literature (Kosson, et al. 2002; Kosson, et al. 2014) with applicability to a wide range of materials and uses. A major achievement of LEAF was the extensive documentation of the technical basis (Garrabrants, et al. 2010) and interlaboratory validation process of four new U.S. Environmental Protection Agency (EPA) test methods that resulted in common practice characterization tests of wastes in general, and fly ash in particular (Garrabrants, et al. 2012a; Garrabrants, et al. 2012b). Analogous test methods are available in Europe through the European Committee for Standardization (CEN) for use in evaluation of waste, soil, sludge, and construction products (van der Sloot 2003; van der Sloot, et al. 2008).

The four leaching tests contained within LEAF comprise:

- Method 1313: Liquid-Solid Partitioning as a Function of Eluate pH Using a



Figure 1. Israeli coal fly ash use in 2017. Quantities of each type of application are presented in thousands of tons and in percentage of fly ash used.
 SOURCE: NCAB (Asphalt, Concrete, and Cement), P.Fine (Sewage), and Ackerstein (Building Products)

- Parallel Batch Extraction Procedure (EN14429 or EN14997)
- Method 1314: Liquid-Solid Partitioning as a Function of Liquid-to-Solid Ratio Using an Up-Flow Percolation Column Procedure (EN14405)
- Method 1315: Mass Transfer Rates in Monolithic and Compacted Granular Materials Using a Semi-Dynamic Tank Leaching Procedure (EN15863)
- Method 1316: Liquid-Solid Partitioning as a Function of Liquid-to-Solid Ratio Using a Parallel Batch Extraction Procedure (partly EN12457-1 and 2)

LEAF includes the program LeachXS Lite™ for database management, enabling comparisons of leaching data for different tests or materials, including outputting data to Microsoft Excel®. LeachXS Lite is available for free licensing and is based on the LeachXS™ platform. The full-featured software in LeachXS Pro allows for advanced modeling and data management capabilities beyond the features included in LeachXS Lite and is licensed for an annual fee.

In the last several years, the Geological Survey of Israel (GSI) has been leading the incorporation of LEAF (data management and leaching test methods) into coal fly ash monitoring (Teutsch, et al. 2017) and research together with Professor David Kosson (Vanderbilt University) and Dr. Hans van der Sloot (van der Sloot Consultancy), who are among the development team of LEAF.

High Fly Ash Content in Concrete and Cementitious Materials

Fly ash is commonly used as a substitute material in cementitious mixtures that, when used in infrastructure applications, may come into contact with runoff, infiltration, and groundwater. This research focuses on leaching of constituents of

potential concern from two types of cementitious mixtures—controlled low strength material (CLSM) and grout—which are commonly used in Israel and contain high fly ash content. The CLSM contains much lower concentrations of fly ash (~20 wt.%) compared with the grout (~45 wt.%).

Cubic specimens made of cement mixtures containing fly ash and control mixtures with no ash were manufactured and cured for periods of 7, 28, and 90 days. After curing, the cubes were tested according to procedure EA NEN 7375:2004 (“tank test”; equivalent to U.S. EPA test Method 1315) for determination of the leaching rate and the extent of inorganic components. The Colombian fly ash CMC-CerD was chosen for its high concentration of contaminants and its low pozzolanic activity as a bounding case.

The initial stages of leaching, especially for the 7-day curing, show substantial variation in pH and conductivity values. The contents of 20 trace elements, mainly constituents of potential concern, were measured in the eluates from the monolith, and the cumulative releases for the entire monolith test were determined. These values can be used to evaluate environmental safety of cementitious mixtures containing fly ash following a scenario-based approach. The U.S. EPA pH dependence leaching test Method 1313 and total content analysis were applied for characterization of the materials (the fly ash and both cementitious mixtures with and without fly ash).

The fly ash composition, which is considerably different than the CLSM and grout reference mixtures, strongly affected the chemical composition of the CLSM and grout blends containing fly ash—and to a greater extent than the difference between the types of blends. Monolith leaching of constituents of potential concern from the CLSM containing fly ash was mostly higher than

from the cement grout mixture containing fly ash because of the effect of the lower percentage of portland cement in the CLSM.

Preliminary results based on rainfall data from different climatic regions in Israel combined with the leaching data indicate that even in the case of high content of fly ash with upper-bound levels of constituents of potential concern, no environmental safety concerns exist from leaching of constituents of potential concern in the Israeli environment.

Use of Fly Ash “As-Is” as Fill Material in Infrastructure

One of the main potential uses of fly ash in infrastructure works involves the use of fly ash as a fill material in road and railroad embankments. The process of embankment filling is undertaken by compaction of the fly ash with the addition of approximately 10% water. With time, the fly ash is susceptible to natural cycles of wetting and drying. The aim of this project is to prepare and examine fly ash samples in conditions similar to the material life cycle in the infrastructure application.

The preparation of samples follows common field practice and aging under different atmospheric environments. The samples are tested by the EPA leaching tests (that is, Methods 1313, 1314, and 1315) at the different stages of sample progress, from loose fly ash through to the final monolith product that has undergone aging under designated conditions. This project is currently in progress and is being carried out together with Professor Konstantin Kovler (Israel Institute of Technology) and Dr. Raphael Yaron (Aram Engineers, Israel).

Trace Element Leachability from Soils Amended with Coal Fly Ash

Following the Convention for Protection of the Mediterranean Sea against Pollution (Barcelona Convention), the Tel Aviv metropolitan area wastewater treatment plant (SHAFDAN) had to decrease its direct sewage sludge discharge into the Mediterranean Sea. One solution for the raw sewage sludge (RSS) was to blend it with coal fly ash and add lime to produce an agricultural fertilizer (Logan and Harrison 1995). The resulting N-Viro Soil® (NVS) product is a beneficial soil amendment.



Figure 2. Mini-lysimeters experiment designed for lettuce cropping and leachate collection: (a) overview of the greenhouse lettuce experiment, each 50 L bucket hosted four mini-lysimeters. (b) Lettuce was grown in 1.5 L containers. Drainage water from each container was individually collected.

SOURCE: A. Moshe (a) and P. Fine (b)

It contains essential plant-available macro and microelements and improves soil physicochemical and biological characteristics (Adriano and Weber 2001; Shen, et al. 2008; Su and Wong 2004).

The potential benefits of NVS are improved plant productivity at lower cost than commercial fertilizers, improved soil structure, and disinfection of infested soils (Fine, et al. 2014). However, concerns have been raised about the safety of NVS over potential: 1) uptake of toxic elements by plants; 2) salinity and toxic constituents degrading planting bed and groundwater; and 3) long-term damage to soil quality (Fine, et al. 2014). Our overall work objective is to assess the relative role of NVS components, fly ash, and RSS on potential uptake by test plants and leaching to groundwater of constituents of potential concern, as well as to determine the safety of NVS in agricultural applications.

In addition to EPA Method 1313 (leachability at different pH levels; Garrabrants, et al. 2012a) and EPA Method 1314 (column testing at L/S ratio up to 10; Garrabrants, et al. 2012b), the project includes a greenhouse mini-lysimeters experiment with romaine lettuce (*Lactuca sativa* L.) as a test crop (refer to Figure 2). The same materials are employed in all three experiments, comprising two soils (dune sand and the plough layer of a clayey vertisol) amended with two levels of NVS based on nitrogen (N) content. The low level was the Israeli annual maximum permitted load (500 kg N/ha), and the high level was five times greater (2500 kg N/ha). The fly ash chosen (F type Colombian La Loma) represents a worst-case-contaminants scenario for fly ashes available in Israel and suitable for NVS production. Untreated soils and soils mixed with the two NVS primary components (fly ash and RSS) served as controls. A further percolation column laboratory experiment modeled after Method 1314 tests the addition of a soil layer to attenuate leached constituents. In a two-layer ported column, the eluent from the soil containing the NVS mixture passes through an unamended soil layer to examine the attenuation of leached constituents immediately below the NVS application.

Leaching concentrations are compared to Israeli standards for drinking (DWI; Ministry of Health 2013) and long-term irrigation (IWI; Ministry of Health 2010) water. These values are maximal as, in nature, attenuation and dilution will considerably reduce the concentrations discharged to the subsoil and to groundwater. Furthermore, in field application of NVS, prior to seeding and seedling, it is applied to the soil and watered until attaining stable pH and conductivity of the soil solution. Consequently, the greenhouse experiment trace-elements concentrations in the leachates are expected to be higher than the plough layer under field conditions.

The NVS is rich in Si (42%), Al (16%), and Fe (5%) contributed by the fly ash, high organic matter content (23%) as a result of the RSS, and Ca (9%) from the CaO and other components. The NVS being a mixture of RSS, fly ash, and lime is reflected in its chemical composition. The U.S. EPA 1313 and 1314 leachability tests indicate elevated concentrations of microelements released from fly ash and NVS. In both ported columns of clayey soil and sand dune, the layer of raw soil reduces the levels of leached constituents of potential concern compared to a regular mixed

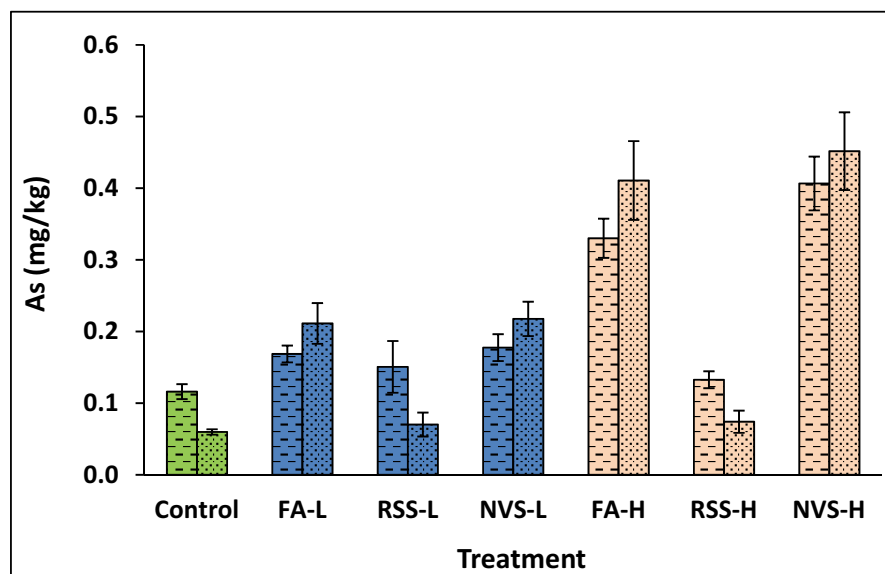


Figure 3. Arsenic concentration in lettuces grown on the different media. All were well below the Israeli ceiling concentration (5 mg/kg dry matter) in leafy vegetables. Control = no lettuce; fly ash (FA), RSS, and NVS were tested at low (L; 500 kg N/ha) and high (H; 2500 kg N/ha) loads; left column - clayey soil (lines), right column - dune sand (dots).

soil–NVS column (the amount of NVS was kept the same in the two packing modes).

In the NVS mini-lysimeters experiment, even in the extreme case of the first eluent from the soil amended with the high load of NVS (five times that permitted, which is not a realistic scenario), the concentrations of all elements of concern were below the ceiling value for long-term irrigation water (IW). The exception is B, which could not be evaluated because it was added as fertilizer.

Lettuce was used as the test crop in the mini-lysimeters experiment owing to its sensitive response to environmental contaminants. All lettuce plants were safe for human consumption because all of the monitored elements were less than the ceiling concentrations for leafy vegetables of 1 mg Cd/kg, 1.5 mg Pb/kg, and 5 mg As/kg (Ministry of Health 2010b; Fig. 3).

This project was the MSc thesis of Alon Moshe (Moshe 2018), and the mini-lysimeters greenhouse experiment was conducted in collaboration and supervised by Dr. Pinchas Fine (Agricultural Research Organization, Volcani Center).

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Punching Above its Weight: Australian Innovation and Latrobe Magnesium

By David Paterson

While the principal output from the combustion of coal is energy, significant quantities of by-products in the form of coal combustion products (CCPs) are also produced. In life cycle terms, the opportunities to exploit the low embodied energy in CCPs such as fly ash, furnace bottom ash, boiler slags, and cenospheres are extensive.

Australian producers and marketers of power station ash formed the Ash Development Association of Australia (ADAA) with the objectives of conducting research, transferring knowledge, and engaging with key influencers and stakeholders to develop market opportunities for CCP use. Advancing the use of CCPs around the world is a challenge that must be embraced to meet the expectations of a circular economy. The ADAA features one of its more innovative and non-traditional market sector members in Latrobe Magnesium (LMG). LMG is currently developing a world-first venture, establishing a magnesium production plant from brown coal fly ash in Victoria's Latrobe Valley using its patented hydromet extraction process and newly developed fast-cycle vertical retort furnace.

The LMG project involves the extraction of magnesium and the production of a supplementary cementitious material (SCM) from the brown coal fly ash that is generated by the Latrobe Valley power stations. The world's first patented extraction process will also be used to reclaim, reprocess, and rehabilitate the coal combustion product storage ponds.

LMG adopts both an industrial ecology and circular economy model. The project:

- Reduces raw material and ash management costs;
- Earns new revenue from by-products;
- Diverts unused by-products from storage and reduces carbon emissions; and
- Opens up new business opportunities.

Some 95% of the fly ash can be converted into:

- Magnesium (10%); and
- SCM (85%).

LMG is also investigating the conversion of the remaining fly ash, comprising char and silicon, into other beneficial products, dependent upon the chemistry of the brown coal fly ash.

Project Timetable

LMG's objective is to create a new viable industry based in the Latrobe Valley reclaiming stored brown coal fly ash (resource) with locally developed technologies (infrastructure) and local employment (intellectual capital) at a cost that is competitive to Chinese manufacturers.

LMG's current development timetable is summarized as follows:

- August 2018—conduct vertical retort test work, complete feasibility study, and finalize funding;
- September 2018—start construction of 3000-(metric)-tons-per-annum plant;
- September 2019—commence production at 3000 tons per annum;
- July 2020—expand to 40,000 tons per annum; and
- July 2021—commence full production.

Products and Markets

I. Magnesium

Magnesium is commonly known as the "green metal" owing to its low weight and strength characteristics. Magnesium has the highest strength-to-weight ratio of all common structural metals. It is one-third the weight of steel and is 33% lighter than aluminum. It has been used historically for desulfurization of steel and in aluminum for strengthening cans. It is increasingly used in the automotive business to reduce the weight of cars, allowing them to go farther, faster, and emit less CO₂.

The automotive industry is being driven by new vehicle emission standards enacted in the United States and those that will be introduced in full by 2020 in the European Union.

China currently produces 86% of the world's magnesium. The following regions/countries' imports from China, in metric tons per annum, are shown in the below table:

U.S. and North America	150,000
Europe	160,000
Japan	40,000
Australia	8000

LMG has a memorandum of understanding with a major Japanese trading house, as well as an off-take agreement with a respected U.S. company, to distribute its magnesium in North America. There is currently only one magnesium producer in the United States.



Prototype of the fast-cycle retort, which includes furnace, retort, and condensers.

SOURCE: Latrobe Magnesium Ltd.

2. Cement Market

The project's SCM has the same chemistry and mineralogy as portland cement. Tests to date have concentrated on substituting 30% and 40% of the cement used in making concrete with the project's SCM to reduce both the costs and the CO₂ emissions associated with making concrete.

3. Carbon Credits

The project is a low CO₂ emitter owing to the magnesium in the fly ash being in MgO form rather than MgCO₃. Similarly, the feedstock for the company's SCM is CaO instead of CaCO₃. The project's emissions are close to 70% less than the industry average for these two products.

Details of Latrobe Magnesium's progress, as well as that of other members, are published in the ADAA's bimonthly e-newsletter, *Coal Ash Flash*. To subscribe to the publication, visit the ADAA website, www.adaa.asn.au, and click the

"subscribe" button on the left side.

The ADAA values its long and close working relationship with the American Coal Ash Association, which contributes toward our shared international interests of providing mutual benefits to industry members, the environment, and the community.

To contact the ADAA, please email publications@adaa.asn.au or call +61 2 4228 1389. ♦

David Paterson serves as the Chief Executive Officer of Latrobe Magnesium. He is a qualified non-practicing chartered accountant and a graduate of the University of Queensland. He is also the Director of Europacific Corporate Advisory Pty. Ltd. and has been involved in a wide range of corporate advisory assignments and underwritings of both debt and equity for a number of public and private companies.

Limited Availability of Cementitious Materials Could Impact the Value Chain

By Dr. Vassiem Sheikh

In 1824, Joseph Aspdin filed a patent on hydraulic cement that he called “portland cement” because its color resembled the stone quarried on the Isle of Portland near the British coast. Aspdin’s production method involved the careful proportioning of limestone and clay, pulverizing them, and burning the mixture into clinker, which was then ground into finished cement.

Today, raw materials—limestone with small quantities of clay and sand—usually come from a quarry located near the manufacturing plant. The materials are blended in the correct proportions, ground together, and heated in an industrial furnace called a kiln to form clinker. Kilns reach temperatures of 1450°C (2640°F). Once cooled, the clinker is ground with a small amount of gypsum to produce portland cement.

The availability of suitable raw materials, particularly limestone, shale, chalk, and clay, is critical to cement making. Raw materials must meet stringent quality requirements and be available in large quantities and exploited economically. Cement manufacturing is a highly energy-intensive process that results in the production of carbon dioxide (CO₂). CO₂ is mainly produced when the calcareous raw material is calcined to produce calcium oxide.

Supplementary cementitious materials (SCMs) are industrial by-products or natural products that develop hydraulic properties when mixed with portland cement. Their chemical composition is of similar nature to portland cement—calcium silicates and aluminates—although proportions of constituents vary. In general, cementitious materials are used to replace clinker in blended cements that allow a reduction in CO₂ and provide additional benefits in terms of cement performance. Their use also provides additional benefits in terms of enhancing the performance of ready-mix concrete. These include improvements in workability, lower heat of hydration, compressive strength, and enhanced long-term durability.

Major Sources of Industrial and Natural Cementitious Materials

Granulated Blast-Furnace Slag from Pig Iron Production

Production of high-quality iron in an efficient furnace is the basis for good blast-furnace slag. After being tapped from the furnace, the slag is cooled, with the cooling rate of the molten material determining its physical and chemical characteristics.

There are two primary methods of cooling. One is to leave the slag to air cool on a stockpile over many days, producing a material that is ideal for processing as an aggregate. Alternatively, instantaneous cooling by quenching with large volumes of cold water produces a material that has, subject to processing, good cementitious properties. This material is normally referred to as granulated blast-furnace slag (GBFS) and is either used as a direct replacement of clinker or ground to be used as a direct addition to ready-mix concrete.

Fly Ash from Coal-Fueled Power Stations

Fly ash material solidifies while suspended in the exhaust gases and is collected by electrostatic precipitators or filter bags. Because the particles solidify while suspended in the exhaust gases, fly ash particles are generally spherical in shape and range in size from 0.5 µm to 100 µm. They consist mostly of silicon dioxide (SiO₂), aluminium oxide (Al₂O₃), and iron oxide (Fe₂O₃). They are also pozzolanic in nature and react with calcium hydroxide and alkali to form calcium silicate hydrates (cementitious compounds).

Two classes of fly ash are defined by ASTM C618: Class F fly ash and Class C fly ash. The main difference between these classes is the amount of calcium, silica, alumina, and iron in the ash. Engineering properties and development of strength over time are different depending on the chemical composition of the fly ash. The chemical properties of the fly ash are largely influenced by the chemical content of the coal burned (that is, anthracite, bituminous, and lignite).

Pozzolans from Volcanic Ash Deposits

Owing to its pozzolan properties, fly ash is used as a replacement for portland cement in concrete. The use of fly ash as a pozzolanic ingredient was recognized as early as 1914. Before its use was lost to the Dark Ages, Roman structures such as aqueducts or the Pantheon used volcanic ash (which possesses similar properties to fly ash) as pozzolan in their concrete. As pozzolan greatly improves the strength and durability of concrete, the use of ash is a key factor in their preservation.

Global Cement and Cementitious Materials Market

The market for cementitious materials is driven to a large extent by the demand for cement, and the world demand for cement is projected to rise 4.5% per year to 5.2 billion metric

Table 1. World Cement Demand (million metric tons)				% Annual Growth	
Cement Demand by Region	Year 2009	Year 2014	2019(f)	2009-2014	2014-2019
North America	115	136	168	3.4%	4.3%
Western Europe	163	126	142	-5.0%	2.4%
Asia-Pacific	2149	3158	3940	8.0%	4.5%
Central & South America	119	153	190	5.2%	4.4%
Eastern Europe	105	120	139	2.7%	3.0%
Africa/Mid East	358	467	611	5.5%	5.5%
TOTAL	3009	4160	5190	6.7%	4.5%

SOURCE: <https://www.worldcement.com/europe-cis/27082015/global-demand-cement-billion-tons-449/>

tons in 2019. The majority of the gains are in the Asia-Pacific and Middle East regions, driven by an increase in construction activity in developing countries such as India, Vietnam, and Indonesia. The Chinese market continues to be the largest contributor to growth, accounting for more than 50% of the global cement demand.

For the United States, the Portland Cement Association forecasts growth of approximately 3.5% in cement consumption annually over the next three years. But the domestic growth rate calculation is heavily influenced by the federal government, and it will take many months before fiscal stimulus and government infrastructure spending plans become clear. California, the Gulf Coast, and the Eastern coastal regions will likely import the majority of cement in the next few years. These regions could also see the ratio of SCMs rise much faster than inland regions.

Globally, the SCM market is forecast to grow at approximately 4 to 5% per annum. It was valued at \$79.2 billion in 2014, over \$90 billion in 2017, and should reach \$100 billion by 2020. However, a key strategic concern for the cement and concrete industries is that cementitious materials supplies are limited, and in some markets demand is exceeding supply.

Approximately 450 MT of blast-furnace slag is produced annually worldwide; however, only part of this is granulated to produce roughly 300 MT of GBFS. The primary producers are China and Japan, which generate more than 50% of the world's production. The strong demand for GBFS in many global markets has had a dramatic effect on prices, with free-on-board prices recently reaching historical highs.

It is expected that until 2030, imported GBFS will remain available because China has a significant surplus. Other places in the world also have availability. There are potential advantages in the quality of imported GBFS. For example, Chinese GBFS has a higher reactivity than some European sources. On the other hand, a reliance on imports also introduces a security-of-supply risk. Already, China has started to use GBFS for its domestic cement industry and begun using its market position to increase price.

With respect to fly ash, approximately 500 MT is produced annually worldwide—60% of which is generated in India and China—and approximately 300 MT is usable ash. In Europe and the United States, fly ash production is being affected by the closure of many coal-fueled power plants. One of the United Kingdom's eight remaining coal power plants is expected to cease generating electricity in 2018, and the government has laid out new rules that are intended to force the closure of all remaining coal-fueled power plants by 2025. A similar scenario is unfolding in Northern Europe, where plants are either being closed or switched to biomass—leading to an overall shortage of



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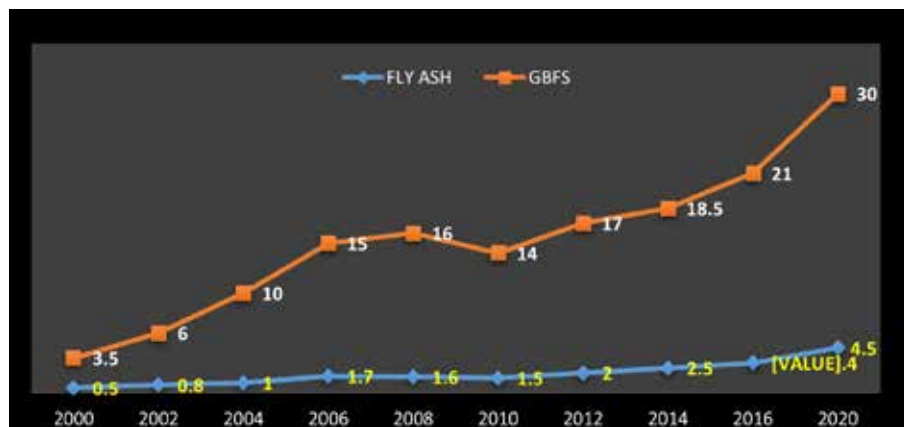


Figure 1. Seaborne Trading of Fly Ash and Slag (MMT)

SOURCE: SCB Europe

fly ash on the continent. This has impacted U.S. markets, which have been large importers of fly ash from Europe.

As coal-fueled power generation diminishes, so does the amount of ash produced. Between 2015 and 2016, as more ash was recovered from landfills—even while some was still disposed—there was a switch from net disposal to net recovery from landfills. In 2016, the UK market required more ash than was produced by power stations or recovered from landfill, and the UK is currently importing ash. In 2017, approximately 250,000 metric tons were imported, compared to 75,000 tons just 2 years earlier.

It has been estimated that there are well in excess of 50 million tons of fly ash deposits in the United Kingdom associated with coal-fueled power stations—either those still in operation or a legacy from power stations that have been shut down. Such deposits have a potential strategic long-term benefit for the UK construction industry. The overall shortage of fly ash in some markets has also opened up new opportunities for the use of pozzolans as a direct replacement for fly ash.

Although fly ash and GBFS are considered the main cementitious materials, there has been a recent increase in the use of ternary blends with both fly ash and GBFS. This combination of both materials in certain proportions in ready-mix concrete has shown superior performance in terms of the workability of fresh concrete to the improved long-term properties of hardened concrete.

Global Seaborne Trading of Cement and Cementitious Materials

According to a recent report by CW Research, more than 174 million tons of cement/SCMs were shipped by seagoing vessels in 2016, up 1.3% compared to the 171.9 million tons shipped by sea in 2015. Its latest research shows that low shipping rates have stimulated seaborne trade. Moreover, the increased imports in key markets where cement production has leveled out (such as the United States) also motivated higher seaborne cementitious trade volumes in 2016 compared to 2015.

Globally, gray cement continues to be the cementitious commodity most heavily traded by sea. In 2016, gray cement comprised

over half of the sea-based cementitious trade (a category that includes gray cement, white cement, slag, clinker, and fly ash). Clinker (including both white and gray) accounted for 33% of total seaborne cementitious trade in 2016, followed by ground blast furnace slag with a 12% share of the trade. Far less traded, white cement and fly ash accounted for 3% and less than 2%, respectively, of total seaborne trade of cementitious materials.

On the main trade routes and regions, Asia-Pacific absorbs 51% of the total seaborne trade of cementitious materials. Due

to proximity and pricing considerations, the largest volumes of cementitious materials were traded within this region, with almost 90 million tons shipped in 2016.

The cost of shipping cementitious materials is a key factor in competitively supplying a customer with fly ash or slag. Today, in most cases, the expense of shipping is greater than the product cost itself and is dependent on bunker (fuel) rates, ship size, and most importantly, the market conditions on the required trading route.

Growing Demand for Fly Ash and Slag

Cementitious materials are commonly used in different stages of the cement and concrete production processes, and the demand for both fly ash and slag is growing. However, due to the lack of availability of these products in some mature markets in the world, the key challenge for the construction industry will be to ensure that sufficient cementitious materials are made available for them to meet their environmental and performance targets.

In Europe and some U.S. coastal states, domestic fly ash production will decline further over the next five years. There are two ways of compensating for this shortage—by recovering fly ash from stockpiles/landfills and beneficiating it using proven technology, or by importing fly ash from other countries where it is available.

Similarly, GBFS production has declined due to the reduction in steel production, which constitutes a vulnerability in the availability of GBFS. This overall global shortage has dramatically increased prices, and it is expected that prices will continue to rise. Importing cementitious materials from countries where there are ample quantities available—that is, India and China—will always be a potential solution to meet shortages. However, there are economic factors to consider, such as freight rates. Moving forward, all stakeholders in the value chain need to be aligned and share a long-term vision for sourcing cementitious materials. ♦

Dr. Vassiem Sheikh is Managing Director of SCB Europe S.r.l. and is responsible for developing the company's international business in Europe, the Middle East, and Asia-Pacific. He has over 15 years' experience in the field of cementitious materials, including global sourcing, supply chain management, and product development.



Beneficial Use Case Study

Spaceport America

Following are case studies documenting beneficial uses of coal combustion products. This will be a regular feature in *ASH at Work* going forward. If you would like to see a recent project from your company profiled in an upcoming issue, please feel free to submit text and (high-resolution) photos to the editor at johnfsimpson@gmail.com. Note that all submissions should include the coal combustion product type (fly ash, bottom ash, etc.), as well as the project name, location, participants, completion date, summary (up to 75 words), and description (300-500 words). We look forward to hearing from you.

Coal Combustion Product Type

Class F Fly Ash

Project Location

Truth or Consequences, New Mexico

Project Participants

New Mexico Spaceport Authority, David Montoya Construction Co., Salt River Materials Group, Guntert & Zimmerman, Virgin Galactic, UP Aerospace

Project Completion Date

September 2010

Project Summary

The New Mexico Spaceport Authority worked with Virgin Galactic, UP Aerospace, and several other aerospace companies to build the world's first commercial spaceport. Spaceport America sits on 27 square miles of state-owned land located in Sierra County, 30 miles east of Truth or Consequences, New Mexico, in the vicinity of White Sands Missile Range. The spaceport was designed with sustainability in mind and met the requirements of LEED Gold Certification. In a weak economy, the spaceport project created approximately 500 jobs.

Project Description

The concrete paving was awarded to Albuquerque-based David Montoya Construction Co. (DMC) and consisted of a 10,000-foot-long runway, taxiways, and aprons. The project began in January 2010 and was completed in September 2010. The 200-foot-wide runway was divided into six 33.33-foot paving lanes, each of which took six days to complete. In order to meet the rigorous job specifications and ensure uniformity and reliability, DMC relied on Guntert & Zimmerman for their concrete slip form paver and batch plant.

Given the location of the spaceport, materials had to be shipped in from hundreds of miles away. Cement was transported from Albuquerque. Approximately 13,675 tons of fly ash was hauled in from Salt River Materials Group's Escalante Fly Ash Facility, near Prewitt, New Mexico. Local aggregates were used in the concrete mixture design.



Source: Salt River Materials Group



Source: Salt River Materials Group



Beneficial Use Case Study

Asheville Regional Airport Temporary Runway

Coal Combustion Product Type

Fly Ash, Bottom Ash

Project Location

Asheville, North Carolina

Project Participants

Asheville Regional Airport Authority, Duke Energy, Charah LLC

Project Completion Date

September 2016

Project Summary

When the Asheville Regional Airport needed to rebuild its only runway, instead of shutting down, they decided to build a new taxiway to serve as a temporary runway during reconstruction. Partnering with Duke Energy and Charah, the airport undertook a massive 85-acre reclamation project using coal ash as structural fill to raise previously unusable land by 40 to 60 feet to airfield elevation for aviation and commercial use. This state-of-the-art encapsulated beneficial-use project saved the airport an estimated \$12 million and avoided approximately 3.5 million cubic yards of borrow excavation and additional land disturbance.

Project Description

In 2009, Charah initiated site development with an environmental assessment following the ASTM E2277-03, *Standard Guide for Design and Construction of Coal Ash Structural Fills*. Under this guide, Charah determined the physical and engineering characteristics of the coal combustion products (CCPs); investigated the geologic and hydrogeologic conditions of the 85-acre site; surveyed for and delineated any pre-existing environmental resources (including jurisdictional streams, wetlands, and cultural resources); incorporated the permitting procedures (local, state, and federal) for the design and construction of the project; coordinated the design and implementation of erosion, sediment, and pollution prevention controls and activities; and followed the testing, engineering, and construction practices for CCP engineered fill projects.

Upon completion of Charah's environmental assessment, in August 2010, engineering commenced on what the industry would consider a state-of-the-art engineered fill facility. This facility featured environmentally conscious controls, such as comprehensive liner-and-cap, leachate collection, and storm-water management systems.

Initial construction activities included clearing, grubbing, and excavation of existing soils to establish the designed subgrade surface. Upon completion of the subgrade surface, Charah began installation of the bottom liner and drainage

collection systems. The bottom liner system included a compacted in-place clay soil subgrade overlain with a bentonite geosynthetic clay liner (GCL) and a 60-mil high-density polyethylene (HDPE) liner. Both the GCL and HDPE liners act as a barrier layer to prevent any CCP material or related moisture from passing through the comprehensive liner system.

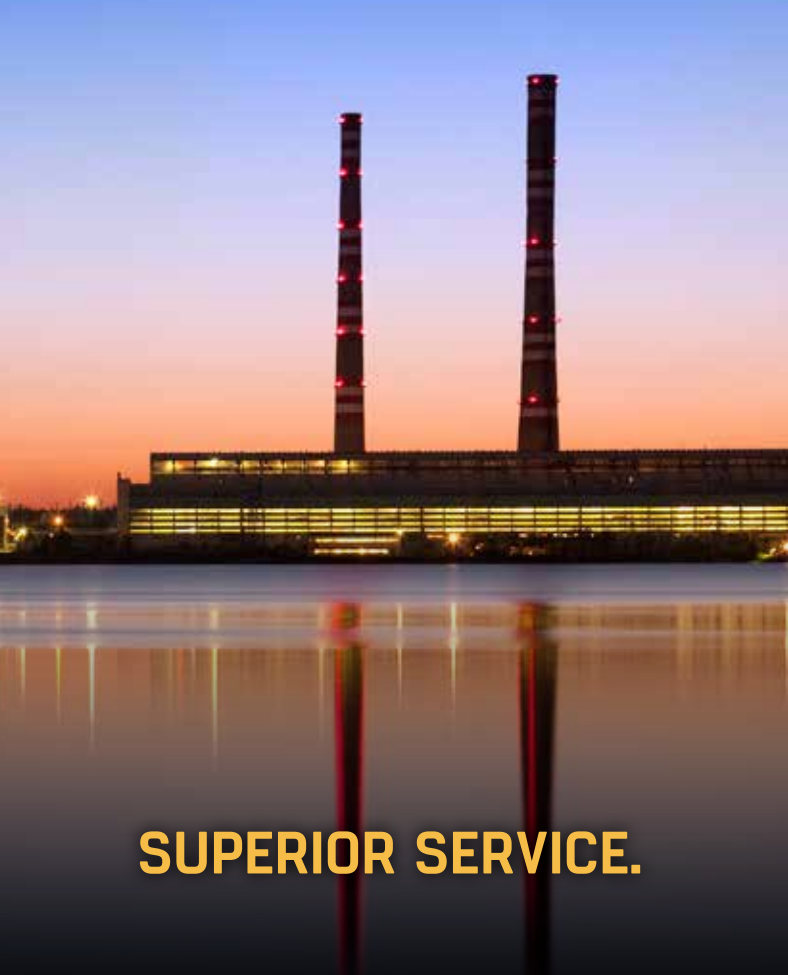
Fill material needed for the project was provided by excavating CCPs from the ash basin located at Duke Energy's Asheville Steam Station less than 3 miles from the airport. CCPs were excavated using long-reach excavators, specially constructed dewatering methods, and traditional excavation techniques and then placed in decant stockpiles located adjacent to or in the ash basin. The CCPs were then allowed to decant to an acceptable level of moisture for transfer, placement, and compaction in the engineered fill at the airport.

CCPs were hauled by dump trucks equipped with tarped beds from the power plant to the fill site. Upon placement, Charah used bulldozers to spread the CCPs in uniform lifts to meet the specified elevation tolerance of ± 0.25 ft. Compaction of the CCP material was achieved using a vibratory smooth drum roller to achieve the compaction requirement of 95% to 100% modified Proctor.

Upon completion of CCP placement, a 40-mil HDPE cap liner was used to encapsulate the material. In addition to the HDPE cap liner, a minimum of 6 feet of compacted soil was placed across the CCP fill limits at a compaction rate of 98 to 100% modified Proctor. This specification met FAA fill placement requirements for the development of utilities, aviation facilities, and infrastructure. While state regulations did not require the use of a comprehensive liner system or an HDPE cap liner when using CCPs as an engineered fill, Charah and Duke Energy considered the application of these design elements environmentally responsible and the only method suitable for this project.



SOURCE: Charah LLC



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Beneficial Use Case Study

Duke Energy Center

Coal Combustion Product Type

Synthetic Gypsum from Duke Energy Used to Make Gypsum Board

Project Location

Charlotte, North Carolina

Project Participants

National Gypsum, Duke Energy, Wells Fargo, tvsdesign, Gensler

Project Completion Date

2010

Project Summary

Duke Energy relocated its headquarters to the second-tallest building in Charlotte, North Carolina. The energy giant's building contains wallboard that started at its own power stations just across the river. The wallboard was made of by-product gypsum from four Duke steam stations—Marshall, Allen, Cliffside, and Bellews Creek—at National Gypsum's Mt. Holly, North Carolina, plant. The building is owned by Wells Fargo.

Project Description

The owner, Wells Fargo, committed to setting new standards for energy efficiency and minimizing the impact of such a monumental structure. Early on, LEED platinum was the goal. When Duke Energy signed on as a primary tenant, there was an opportunity not only to use recycled content for the gypsum board but to also use material produced as a by-product in Duke Energy power plants. National Gypsum's Mt. Holly plant uses by-product gypsum from four Duke Energy power plants.

The architect and contractor required chain-of-custody documentation that all gypsum board would come from National Gypsum's Mt. Holly plant. The gypsum raw material used at Mt. Holly is derived exclusively from Duke Energy power plants as a by-product of coal combustion. The power plants are within 95 miles of Mt. Holly, which is 17 miles from the project site—easily qualifying for regional materials credit for manufacturing and extraction.

In addition to the distinction of LEED platinum for the building, Wells Fargo required all tenants to achieve LEED certification. Duke Energy Center is the largest office building in the world with this requirement. The architect for the tower was tvsdesign. Gensler's Charlotte office designed the interior spaces for Duke, which occupies 21 of the 48 floors.



Source: Wikimedia Commons



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Beneficial Use Case Study

One Light Tower

Coal Combustion Product Type

Class C Fly Ash

Project Location

Kansas City, Missouri

Project Participants

Humphreys & Partners Architects LP, Taliaferro & Browne Inc., Talon Concrete, Kansas City Fly Ash, Kansas City Power & Light

Project Completion Date

December 2015

Project Summary

One Light Tower is a 25-story luxury residential high-rise located in downtown Kansas City, Missouri. The building comprises 311 apartments, all of which have floor-to-ceiling glass. Various floor plans range in size from 590 to 1379 ft² and include the following: studio apartments, one- and two-bedroom apartments, and 24 penthouse units on upper floors. One Light Tower also offers residents a rooftop pool, 2500 ft² of retail space, fireside lounges, and an on-site theater.

engineers employed 16 different mixture designs to meet the structural requirements. The fly ash content in these mixtures ranged from 78 to 308 lbs. per yd³. The concrete strength requirements in these mixtures ranged from 4000 to 8000 psi.

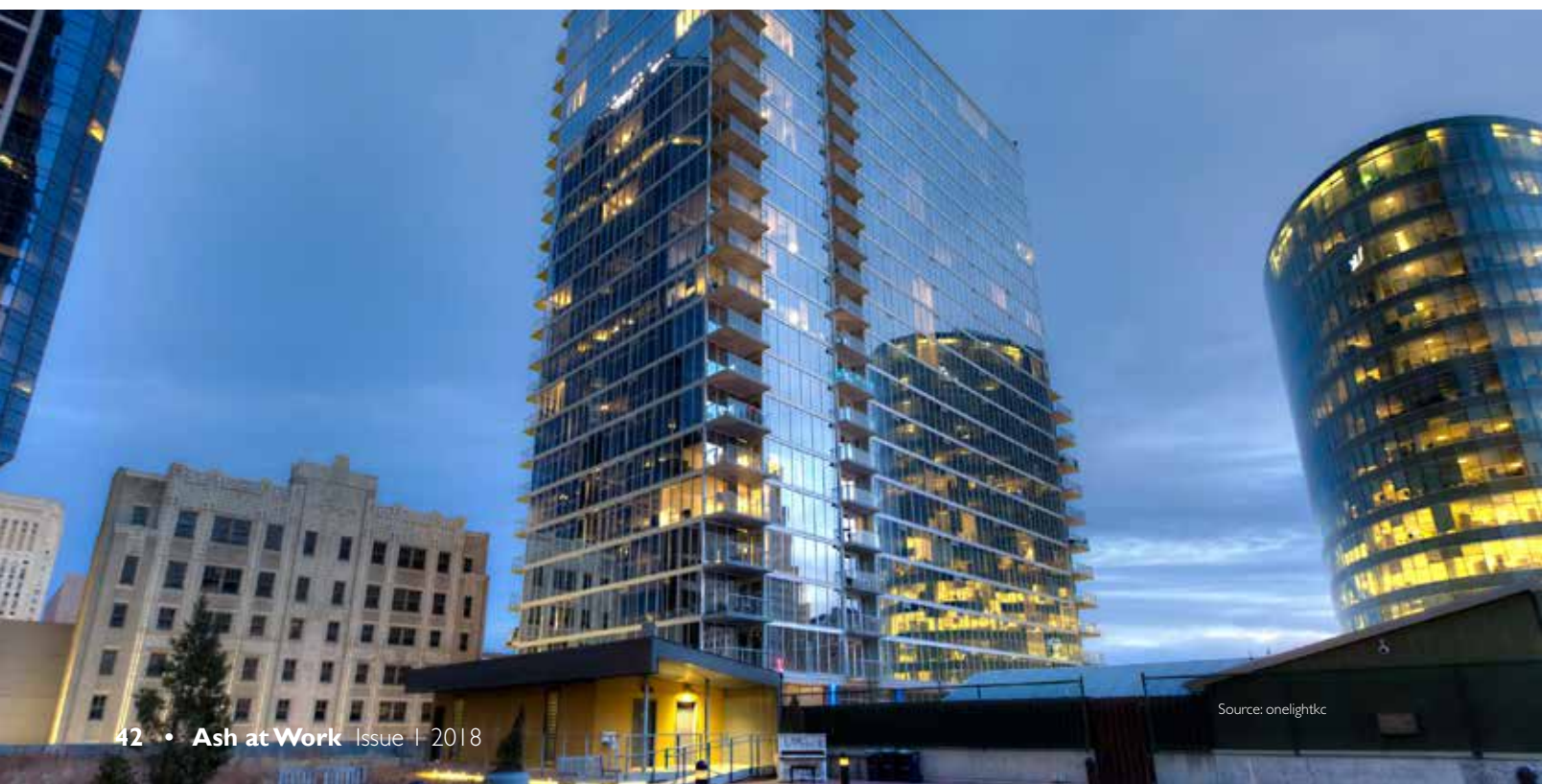
Kansas City Fly Ash and its utility partner Kansas City Power & Light supplied all of the fly ash on this project, which was produced locally and comprised Class C fly ash generated from burning Powder River Basin coal. Talon Concrete's Bunker plant was ideally located to provide timely service and quality concrete to meet an aggressive construction schedule. Talon QA/QC personnel provided real-time expertise to control concrete properties and avoid any quality issues that would have negatively impacted the construction schedule.

The completion of One Light Tower is an example of the revitalization of downtown Kansas City, which has seen a rebirth over the last 15 years. Kansas City now boasts a vibrant downtown area with entertainment, new housing options, restaurants, and a grocery store. Rental occupancy is approximately 99% downtown, and new construction continues to meet this demand.

Project Description

One Light Tower was completed in December 2015 using 13,205 yd³ of concrete and 789.4 tons of fly ash. Design

The success of the One Light project is now being followed up with the construction of Two Light Tower. Talon Concrete is again supplying concrete for the new luxury high-rise using local fly ash.



Source: onelightkc



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Beneficial Use Case Study

Dover Air Force Base Runway Project

Coal Combustion Product Type

Thermally Refined Class F Fly Ash

Project Location

Dover, Delaware

Project Participants

NRG, Allega Concrete Corporation, SEFA Group

Project Completion Date

December 2016

Project Summary

Dover Air Force Base is home to the U.S. Air Force's fleet of C-5s and C-17s—both large military transport planes. The base's north-south runway 01-19 required a complete renovation to extend its lifespan an additional 50 to 75 years—necessitating its shutdown for a year and a half. Runway 14-32 required a partial overhaul. In February 2016, the project reached the stage at which the intersection of both runways needed to be worked on—temporarily cutting 14-32's length from 12,900 ft to 6000 ft and limiting the operational capabilities of Team Dover's C-5M Super Galaxy fleet.

Project Description

This project involved the replacement of 10,000 ft of concrete pavement along runway 01-19, as well as 1700 ft of concrete pavement along the intersection of runway 14-32 and runway 01-19. In addition, taxiways bravo, charlie, delta, echo, and fox-trot were rehabilitated with an average of 4000 yd³ of concrete per day. Thermally refined Class F fly ash was sourced from SEFA's STAR processing plant at Morgantown Generating Station in Newburg, Maryland.

To maximize efficiency and production on the project, Allega mobilized two on-site concrete batch plants. Working in conjunction with each other, they placed over 165,000 yd³ of concrete to manage the large daily production needs. The scope of work on this project entailed over 246,000 yd² of 15 and 20 in. concrete finished pavement and over 257,000 yd² of 5 in. drainage layer concrete.





Beneficial Use Case Study

Salt Lake City Main Library

Coal Combustion Product Type

Ultra-Fine Pozzolan Boral Micron3

Project Location

Salt Lake City, Utah

Project Participants

Moshe Safdie & Associates, Big-D Construction, Jack B. Parson Co., Boral Resources

Project Completion Date

2003

Project Summary

Salt Lake City's main library is a five-story-tall, 240,000 ft², wedge-shaped building. The structure incorporates 44,960 yd³ of concrete, 176,368 ft² of glass, and a five-story curved glass wall.

Project Description

The library had column and beam design strength requirements of 8000, 6000, and 5000 psi, together with 4000 psi lightweight slab concrete mixtures. Architects Moshe Safdie & Associates further stipulated that all finished concrete surfaces should be uniform in color and texture when viewed from a distance of 3 ft. Their specification called for color matching between the concrete mixtures of different strengths.

The project's ready-mix concrete supplier, Jack B. Parson Co., proposed Boral Micron3 among candidate designs for the 8000 psi concrete columns. The product has a mean particle diameter of 3 micrometers with 90% of the particles less than 7 micrometers. The fine particles lead to a high packing density and increased pozzolanic reactivity at an early age, which contribute to high strength and

durability—particularly with respect to corrosion, alkali-silica reaction, and sulfate attack.

Micron3 was effective not only in achieving 8000 psi but also in reducing the water and high-range water-reducing (HRWR) admixture demand and improving concrete workability. Micron3's light color further helped to provide color continuity between the columns and horizontal structural members that were cast from different strength mixtures.

The exposed concrete surfaces in the Salt Lake City Main Public Library project challenged suppliers and contractors to look past their previous concrete experience and consider every variable affecting interior and exterior concrete quality. Boral's ultra-fine pozzolan product proved ideal for meeting the stringent quality, strength, and durability standards.



Source: Salt Lake City Public Library



Source: Wikimedia Commons



Beneficial Use Case Study

Special-Waste Landfill Reclamation

Coal Combustion Product Type

Fly Ash

Project Location

Underwood, North Dakota

Project Participants

Great River Energy, Falkirk Mine, Boral Resources

Project Completion Date

October 2017

Project Summary

An on-site project at Coal Creek Station provided Great River Energy with the opportunity to reclaim fly ash from a nearby special-waste landfill that had been considered inactive and covered since 2005. Use of fly ash from the Section 26 landfill would allow the electric cooperative to fulfill the on-site project's requirements for fly ash without cannibalizing its existing fly ash sales revenue. It also eliminated the need for Great River Energy to allocate funds to close the landfill.

Project Description

When looking at the feasibility of using the Section 26 fly ash—a portion of which had been landfilled almost 20 years earlier—the utility engaged in extensive testing to determine its quality. After confirming the quality, the utility next had to factor in the cost of removing the fly ash.

A major cost saving from using the landfilled ash arose from the fact that the 42-acre lined landfill was required only to

have a temporary protective cover. After the cost savings were determined, Great River Energy had an easy decision and started the reclamation process in the summer of 2016.

The fly ash reclamation work was contracted to a third party, which removed the temporary cover. The reclaimed ash was blended with virgin ash, moisture conditioned, and transported via haul truck to build an FGD upstream raise landfill at Coal Creek Station. Use of the reclaimed fly ash allowed Coal Creek Station to make its new production of fly ash available for the concrete market instead of using it to build the upstream raise.

The fly ash reclamation project generated many benefits for Great River Energy and its member cooperatives, including:

- Avoiding landfill closure costs
- Making available more fly ash for the concrete market
- Declassifying Section 26 as a landfill area and returning it to its original use as agricultural land

In total, the process took over a year to complete, during which Great River Energy reclaimed over 236,000 cubic tons of fly ash from the special-waste landfill. Use of the reclaimed fly ash also resulted in millions of dollars in cost savings.

"Every dollar we save goes back to our cooperative members—we always keep that in mind with everything we do," said Al Christianson, Director of Business Development and Governmental Affairs at Great River Energy. "Not only are we saving money for our members, but we are declassifying a landfill and restoring it to its original intent, which is a win-win for everyone."



Source: Great River Energy

Editor's Note: "Six Questions for..." is a regular *ASH at Work* feature in which leaders with unique insight affecting the coal ash beneficial use industry are asked to answer six questions.

Since 2012, Creative Association Management (CAM), a subsidiary of the American Concrete Institute, has provided association management services to the American Coal Ash Association. In late 2017, CAM merged with Constructive Communication Inc. (CCI)—a public relations and marketing communications firm with extensive industry experience. The new entity—Advancing Organizational Excellence (AOE)—is uniquely positioned to offer clients such as ACAA full-service support with expertise in association management, event planning, marketing and public relations, crisis communications, operations, as well as training and educational services expertise.



Kimberly Kayler, CPSM, President and Founder of CCI, was named President of AOE. A marketing professional with extensive experience serving technical industries, Kayler worked in business development and marketing communications roles at engineering firms and as an editor at Wright-Patterson Air Force Base before she started CCI to serve the needs of professional service and business-to-business technical firms. In her role as President of CCI, she helped clients define strategy and develop marketing action plans. CCI's client list included more than two dozen design and construction-related organizations and associations, as well as companies in the chemical, aerospace, and industrial sectors.

Ash at Work (AW): What inspired you to found Constructive Communication Inc. in 2001?

Kimberly Kayler (KK): Having worked in various marketing roles for engineering firms and other technical organizations, I saw the need for a consulting firm that truly specializes in the industries it serves. To this end, all my team members have immense experience in the concrete, construction, architectural, chemical, industrial, oil and gas, and other technical/scientific fields. As the purchaser of marketing and management consulting services during my tenure at two different engineering firms, I grew to appreciate how important and rare it is for consulting firms to have a true expertise in our industry. Marketing a retail product to consumers is vastly different than selling professional services or educating government stakeholders about our industry.

AW: The merger of CAM and CCI brings a full menu of services and expertise unmatched in the construction industry. How did the AOE concept develop?

KK: The AOE Board of Direction wanted to round out the service offering of CAM and I am a long-time volunteer with

ACI, having served on its Board of Direction and as Chair of the Marketing Committee and several task groups. My role is to handle the day-to-day operations of AOE and be an advocate for our clients. I work for you: the ACAA Board and its members. We are honored to have ACAA as a client.

AW: Since its founding in 2001, CCI served numerous clients. In your experience, do you find that clients really understand their needs when they first contact your firm?

KK: This is a great question, and in many cases the answer is no! For example, I may be contacted by a concrete contractor saying they want help with an ad or a brochure, and when I spend time reviewing their target audiences, key messages, and goals, I may find they would be better served by a speaking opportunity at a local association or an article in a trade publication. Ensuring the strategy step is not skipped is key, as too often we all just go straight to tactics.

AW: Crisis communications was a particular strength of CCI for a long time. Planning for response to a crisis is highly recommended. Is the industry getting better at the planning process?

KK: Unfortunately, even the best of intentions related to crisis planning often aren't good enough in today's age because of the speed at which news travels through social media and online reporting. If your crisis plan doesn't address social media or other online news outlets, it is essential for the plan to be updated. Having helped organizations with crises ranging from job site fatalities and chemical spills to embezzlement and other scandals, I can attest to you that those with a crisis plan and training fared far better than those having to assemble a plan on the fly.

AW: Strategic planning can be a very valuable process when done properly. What are the biggest mistakes organizations make when creating strategic plans?

KK: Trying to tackle too much and not aligning business and marketing objectives. The marketing strategy in the plan should support the business plan, and both should support the vision and mission of the organization. There should be no more than three, maybe four goals. You can have an unlimited number of tactics to support each goal, but be really careful about having too many goals as efforts get diluted.

AW: All work and no play is not a formula for a healthy life. What do you do in your spare time to provide balance to your life?

KK: I am a registered yoga teacher on the side, so I find balance, literally, doing and teaching yoga. The mother of two college-aged sons, I enjoy spending time with both of them—we all love to travel. Other hobbies include stand-up paddleboarding and hiking with my dog.

AW: Thank you, Kimberly.

In & Around ACAA



Washington, DC

A well-attended news conference at the National Press Club (November 21, 2017) was the setting for the release of the American Coal Ash Association's annual coal ash Production and Use Survey results. Thomas Adams, ACAA Executive Director, presented the 2016 data to national and trade publication reporters.



Sarasota, FL

The American Coal Ash Association Women's Leadership Forum met during ACAA's Winter Meeting January 30-31, 2018. The Forum is an informal group of ACAA women members whose broad goals are to develop interest and qualifications of women for ACAA committee leadership and officer positions; to acquaint members with the wide range of energy and building materials careers, professional organizations, and meetings with the goal of opening paths for further career development; and to promote professional interactions and camaraderie among members and women in related fields, including government, energy, building materials, and consulting.

In Memoriam

Alice Lynne Marksberry passed away December 6, 2017, in Louisville, Kentucky, at age 53 after a courageous battle with cancer. She was interred at the Owenton Cemetery in the Marksberry family plot.

Alice worked for over 20 years for the Center for Applied Energy Research (CAER) at the University of Kentucky (UK), where she was the primary event coordinator for many technical events, including the World of Coal Ash. A UK graduate with both bachelor's and master's degrees, she began working at CAER while pursuing her graduate degree in library science.



Richmond, VA

More than 200 people attended the "Current Issues in Pondered Ash" workshop March 20-21, 2018. Jointly sponsored by the American Coal Ash Association, University of Kentucky Center for Applied Energy Research, and Electric Power Research Institute, the workshop was the third well-attended event on this topic since U.S. Environmental Protection Agency coal ash disposal regulations were finalized in 2015. A fourth event is planned for Louisville, Kentucky, October 30-31, 2018.

WOCA 2017 is the Largest in History!

A record 1018 attendees convened at WOCA 2017 in Lexington, Kentucky, as academic, industrial, and research leaders descended upon the Bluegrass State for the world's premier conference on coal ash and by-product utilization.

WOCA, held May 8-11, featured the opening plenary session, exhibitor hall filled to capacity, seven daily parallel technical sessions, a poster session, and numerous social activities embedded throughout the agenda to ensure a fast-paced, lively meeting.

"What separates WOCA from most meetings is that everyone is under one roof," said Tom Robl, senior technical fellow at the University of Kentucky Center for Applied Energy Research and a founder of WOCA. "You have industry leaders sharing their perspective from the marketplace. Researchers are presenting the latest and greatest in discovery and innovation. And students bringing their unique perspective to the meeting. That diversity and creativity fuels the meeting."

More details about the biennial meeting follow, and we look forward to seeing everyone at WOCA 2019.

WOCA 2017 AWARD RECIPIENTS

The following individuals were recognized at WOCA 2017:
Barton A. Thomas Memorial Award for Best Oral Presentation: Christopher W. Swan, Tufts University
Sponsored by the University of Kentucky Center for Applied Energy Research

WOCA Poster Award: Ji Young Lee, University of Seoul
Sponsored by the Electric Research Power Institute

WOCA Student Oral Presentation Award: Xenia Wirth, Georgia Institute of Technology
Sponsored by the Midwest Coal Ash Association

WOCA Student Poster Award: Wenlong Zhang, Georgia Institute of Technology

Sponsored by the American Coal Ash Association Educational Foundation

MCAA Stipend Award Winners (each \$500 stipend sponsored by the Midwest Coal Ash Association)

- James Locum, Tennessee Tech University
- Sarah Hodges, University of Kentucky Center for Applied Energy Research
- Madison Hood, University of Kentucky Center for Applied Energy Research

iPad Winner: Tony Moran, Geo-Solutions Inc.

Tony is the winner of the iPad drawing for individuals who reserved a room(s) through the WOCA room block.

WOCA 2017 PAPERS NOW AVAILABLE

The WOCA 2017 submitted papers are now available on the Ash Library proceedings website: www.flyash.info.



Paul Kish of the Midwest Coal Ash Association presents checks to MCAA stipend award winners (l-r) Madison Hood, Sarah Hodges, and James Locum.







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Service Above All.

Coal Ash Recycling Reaches Record 56% Amid Shifting Production and Use Patterns

Fifty-six percent of the coal ash produced during 2016 was recycled—establishing a new record and marking the second consecutive year that more than half of the coal ash produced in the United States was beneficially used rather than disposed.

“The trend for coal ash beneficial use continues to be very positive,” said American Coal Ash Association Executive Director Thomas Adams. “For the third straight year, we have seen significant improvement in the beneficial use rate.”

According to ACAA’s Production and Use Survey, 60.2 million tons of coal combustion products (CCPs) were beneficially used in 2016 out of 107.4 million tons produced. Although the rate of ash utilization increased from 52% to 56%, the total volume of material utilized stayed about the same as production declined. Coal ash production volume declined 7% from 2015 levels as coal’s share of the electricity generation mix shrank in response to environmental regulations and competition from other energy sources. Coal ash utilization volume remained approximately level with the prior year.

Highlights of CCP production and use in 2016 included:

- Use of coal fly ash in concrete declined 8% to 14.4 million tons. While down from 2015’s record utilization of 15.7 million tons, utilization remained well above the 13.1 million tons performance in 2014. The dip in 2016 utilization is attributed to some regional seasonal shortages of supply that resulted from power plant shutdowns and changing generating profiles. Demand for fly ash remained strong across all concrete markets, and utilization likely would have been higher if some logistical disruptions had not occurred.
- Utilization of a key “non-ash” CCP also declined. Use of synthetic gypsum in panel products (i.e., wallboard) decreased 19% to 9.9 million tons in 2016. The decrease is largely attributed to normal fluctuations in gypsum markets. During 2016, gypsum imports increased by 15% versus 2015, whereas exports decreased by 27%—thereby creating greater

competition from natural gypsum. Synthetic gypsum use in agricultural applications also declined from 1.6 million tons to 772,000 tons.

- Production of boiler slag remained level at 2.2 million tons. Approximately 1.3 million tons of boiler slag was utilized in the production of blasting grit and roofing granules.
- For the first time, no utilities reported production of cenospheres—a very valuable form of ash harvested mainly from wet disposal impoundments. Production of this material dropped precipitously the year prior as impoundments began to close in response to EPA’s Final Rule for coal ash disposal.

According to Adams, increasing beneficial use requires ash marketers to ensure that products are consistent and available when customers need them—requiring large investments in technology and logistics. Additionally, the coal ash beneficial use industry is actively developing and deploying technologies and strategies for reclaiming coal ash materials that were previously disposed.

ACAA Comments on EPA Disposal Rule Reconsideration

The American Coal Ash Association filed written comments and presented oral testimony at a public hearing concerning the U.S. Environmental Protection Agency’s (EPA’s) “phase one” proposal to revise coal ash disposal regulations.

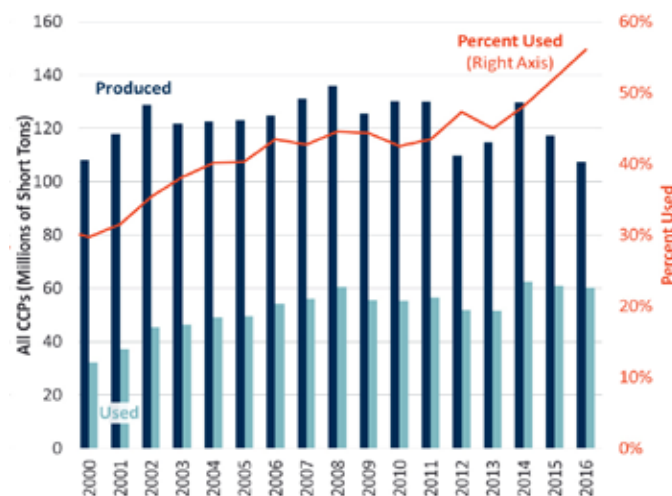
On March 15, 2018, the agency published in the Federal Register the first of two rules that will amend the regulations for disposal of coal combustion residuals (CCRs) by electric utilities and independent power producers. The proposed rule includes more than a dozen changes to the 2015 final CCR Rule, which established minimum national standards regulating the location, design, and operation of existing and new CCR landfills and surface impoundments at more than 400 coal-fueled power plants nationwide. EPA also plans to propose additional changes to the CCR Rule later this year.

Although most of the proposed revisions in phase one of EPA’s rule-making concern disposal issues, ACAA pointed out that EPA is bound by purpose, statute, and agency precedent to consider impacts on beneficial use in the development of its coal ash disposal regulations. “Beneficial use of CCRs is a key component in improving the sustainability and economic productivity of numerous segments of the U.S. economy,” ACAA’s comments said. “If it is EPA’s objective to use environmental policy to encourage sustainability and economic productivity, then it cannot ignore the impacts on a sector that accounts for the management of 56% of a large resource base, even if the primary focus of the rule proposal is disposal.”

ACAA highlighted three major concerns in its comments:

- EPA should enact extensions of compliance deadlines for the current CCR Rule while proposed amendments are finalized and state permit programs are proposed and approved.
- Use of CCRs in closure of disposal units constitutes a beneficial use under EPA’s definitions and therefore is already exempted from regulation.
- Amendments to EPA’s coal ash disposal regulations should specifically allow for and encourage reclamation of CCRs from active and closed disposal units for beneficial use.

All CCPs Production and Use with Percent





“Beneficial use of CCRs is a key component in improving the sustainability and economic productivity of numerous segments of the U.S. economy,” ACAA noted in its comments to EPA.

ACAA was represented at the Washington, DC, public hearing on the rulemaking proposal by Danny Gray of Charah LLC. For copies of ACAA’s written or oral comments, contact Government Relations Committee Chair John Ward at wardo@wardo.com.

ASTM Standard Guide Development for Reclaimed Ash

American Coal Ash Association representatives accepted an invitation to speak at the mid-year meeting of the Association of State and Territorial Solid Waste Management Officials on April 25, 2018, attended by approximately 250 state and federal environmental regulators. ACAA Executive Director Thomas Adams and Government Relations Committee Chair John Ward presented information on coal ash beneficial use and the rapidly increasing interest in reclaiming ash for beneficial use from landfills and impoundments. In addition to discussing market trends for ash utilization, ACAA’s presentation summarized strategies for ash reclamation and efforts within ASTM to develop a standard guide for harvesting ash resources.

ASTM Subcommittee E50.03 on Beneficial Use met earlier in the month to discuss negatives and comments on the ballot to approve the proposed standard guide for “harvesting coal combustion products stored in active and inactive storage areas for beneficial use.” Voting on the draft document closed in February.

The draft standard guide defines coal combustion products, gives examples of potential beneficial uses, and describes ash

storage methods, including ponds and landfills. More specifically, it provides:

- A framework to address critical aspects related to the harvesting of CCPs situated in active and inactive storage areas for beneficial use.
- Harvesting guidance for CCPs, including evaluation of storage areas for harvesting, detailed characterization of CCP storage areas, planning and scoping of harvesting projects, detailed design and approval (if required) of CCP storage area harvesting, and implementation of harvesting.
- Guidance related to the operational aspects of harvesting CCPs, such as management of contact water and fugitive dust controls during the harvesting process.

If CCPs stored in active or inactive storage areas are characterized and determined to meet product specifications and performance standards (with or without conditioning) for use as an ingredient in lieu of raw materials or used on their own, they may be harvested and directed to beneficial use applications. This can provide industry with a safe and responsible way to economically manage CCPs, while promoting conservation and recycling/reuse, as well as meeting sustainability goals. Beyond this, these storage areas may (or may not) be regulated under local, state, and/or country programs, and alternate closure of CCP storage areas via harvesting can allow for the repurposing of the land for reuse and assist with potential long-term risk and liability management issues.

2017-18 ACAA Educational Foundation Scholarship Winners Selected

The American Coal Ash Association Educational Foundation awarded \$12,000 in scholarships to five university students with interests in advancing the sustainable and environmentally responsible use of coal combustion products. Scholarship winners represent universities from coast to coast, including:

Shinhyu Kang, a Ph.D. candidate in civil engineering at Oklahoma State University, was selected to receive the \$5000 David C. Goss Scholarship. Kang's application essay discussed predicting performance of fly ash in concrete by using automated scanning electron microscopy.

Livingstone Dumenu, a Ph.D. candidate in infrastructure and environmental systems at University of North Carolina – Charlotte, was selected to receive a \$2500 John Faber Scholarship. Dumenu's application essay discussed laboratory investigation of water-repellency effect on unsaturated properties of compacted coal combustion products.

Sen Du, a Ph.D. candidate in civil engineering at Washington State University, was also selected to receive a \$2500 John Faber Scholarship. Du's application essay discussed facilitating the use of high-volume fly ash concrete in the field.

Siamak Riyazi, a Ph.D. candidate in civil engineering at University of Missouri – Kansas City, was selected to receive a \$1000 American Coal Ash Association Educational Foundation Scholarship. Riyazi's application essay discussed the effect of superabsorbent polymers as an admixture on durability properties of concrete containing fly ash.

Bethany Buckland, an undergraduate in civil engineering at University of Missouri – Kansas City, was also selected to receive a \$1000 American Coal Ash Association Educational Foundation Scholarship. Buckland's application essay discussed the sustainability benefits of coal combustion product use.

The ACAA Educational Foundation is a financially self-sustaining, not-for-profit organization that promotes understanding of CCP management and use through communications and outreach initiatives that are aimed at government and industry decision-makers and the public. Foundation initiatives consist of awarding university-level scholarships, development and distribution of educational materials, financial support for research, and sponsorship of CCP forums. Visit www.acaa-usa.org/aboutacaa/educationalfoundation.aspx for more information. ♦

THANK YOU, JUDGES!

- Tom Adams, ACAA
- Travis Collins (Chair), National Minerals Corporation
- Fred Gustin, Kansas City Power & Light
- Tim Kyper, DiGioia Gray & Associates
- Peggy Rennick, SCB International
- Mike Schantz, Lhoist North America

- John Trast, GEI Consultants, Inc.
- Tristana Duvallet, University of Kentucky, Center for Applied Energy Research
- Mark Rokoff, AECOM
- Laurie Cook, DTE Energy

Benefits of Using Fly Ash as a Supplementary Cementitious Material in Concrete

By Bethany Buckland, Bachelor of Science Candidate, Civil Engineering, University of Missouri-Kansas City

Abstract

The use of combustion coal products as supplementary cementitious materials is a sustainable alternative to previous conventions. Fly ash, a pozzolanic material, is often used in concrete to increase strength and density, as well as reduce heat of hydration. Fly ash offers an economic substitution for portions of portland cement, as it is a waste material that can be purchased at a reduced cost. It also allows for environmental benefits, fulfilling LEED points in infrastructure and being seen as a suitable use of the waste by the Environmental Protection Agency. Fly ash is produced across the globe, making it an accessible material to benefit industry worldwide.

Essay

Fly ash, a coal combustion product, is often used as a supplementary cementitious material (SCM) in concrete. Fly ash is a pozzolanic material, meaning it will chemically react with the calcium hydroxide produced when portland cement mixes with water (Girard 2011). This will create a concrete mixture with high performance. Fly ash is a sustainable material to use in concrete. According to the National Precast Concrete Association, 75% of all concrete is made with some proportion of fly ash (McCraven 2013). Fly ash is a material available worldwide, making it an economical and viable option for increasing strength and durability in concrete across the globe.

There are several benefits to using fly ash as an SCM in the concrete industry. Aside from adding strength, fly ash also increases the density of concrete and reduces the hydration temperature throughout the curing process (McCraven 2013). This is seen as a major benefit, as too much heat during curing can cause premature concrete failure. Using fly ash allows for the reduced use of portland cement, which is the most expensive material used in most concretes.

While there has been some debate as to the classification of coal combustion products as a waste material, there are many environmental benefits to using fly ash in concrete. The United States Green Building Council developed a rating system for environmental performance of buildings called Leadership in

Energy and Environmental Design (LEED) (Portland Cement Association 2010). The use of fly ash in concrete fulfills LEED points (McCraven 2013). The Environmental Protection Agency (EPA) published a beneficial use evaluation for fly ash concrete, stating that its use can help reduce greenhouse gas emissions and use of “virgin resources.” The publication very clearly endorsed its benefits, saying the “EPA supports the beneficial use of fly ash in concrete” (U.S. EPA 2014).

Use of fly ash as an SCM reduces the permeability of concrete, thereby increasing its resistance to chlorides (Thomas 2007). The presence of fly ash in concrete has also shown the ability to reduce creep and shrinkage as well. This increases the durability of the concrete, making it last longer. Use of fly ash in concrete also is of economic value. As a waste material, fly ash can be purchased more cheaply than portland cement, the main material in concrete. Substituting some portion of portland cement with fly ash thus allows a reduction in cost that can easily become significant in large projects.

There are many benefits to the industry, environment, and economy in using fly ash as an SCM in concrete. Not only does it reduce waste through reuse, but it also reduces the cost to produce concrete. Simultaneously, an appropriate proportion of fly ash can produce multiple benefits in the concrete itself, including increasing strength and durability. If similar applications can be found with other coal combustion products, their sustainable use could easily bring benefits across the world. ♦

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Facilitating the Use of High-Volume Fly Ash Concrete in the Field

By Sen Du, Ph.D. Candidate, Department of Civil and Environmental Engineering, Washington State University

Abstract

High-volume fly ash (HVFA) concrete has been widely investigated because of its lower carbon footprint and comparable or even higher performance than the conventional portland cement concrete in most cases. However, the main drawbacks of HVFA concrete—the low early-age strength and reduced resistance to freeze-thaw cycles and salt scaling—hinder its application in the field. In this study, a specific nano-material (graphene oxide) was admixed into HVFA concrete to improve the hydration of fly ash particles and thus enhance the strength development. In addition, several chemical admixtures were added, aimed at refining its pore structure and optimizing the transport properties of concrete, which are considered related to the freeze-thaw resistance.

Introduction

Fly ash, as a main by-product of coal-fueled power plants, is one of the most-used supplementary cementitious materials (SCMs) in concrete. The application of increased proportions of fly ash in concrete makes it a more sustainable and environmentally friendly material, assuming there is no significant sacrifice in performance and durability of the concrete. Admixing fly ash in concrete can not only reduce the carbon footprint and embodied energy of the concrete, but also reduce the hazards it may bring to the environment. The term “high-volume fly ash” concrete was defined by V.M. Malhotra, who proposed that the replacement of cement by fly ash should be 50 wt.% or more (Malhotra 2002).

While numerous investigations of HVFA concretes have focused on case studies of mechanical strength and durability performance, the physical and chemical changes of fly ash and its hydration products in HVFA concretes have not been fully understood. One main drawback reported of HVFA concrete is the low early-age strength (De la Varga, et al. 2012), which is due to the insufficient hydration of fly ash particles (Du,

et al. 2017). There are also studies suggesting that HVFA concrete performed poorly in freezing and thawing and salt scaling tests. Generally, the extent of freeze-thaw deterioration and surface scaling is greatly affected by the intrinsic transport properties of concrete.

In order to increase the early-age strength of HVFA concretes, numerous studies have focused on improving the performance of HVFA concrete by adding nanomaterials. In this study, graphene oxide (GO), one of the graphite-based nano-sized materials, was admixed into HVFA concrete to investigate its effect on fly ash hydration and strength development. What's more, it has been reported that GO can increase the air content and modify the pore structure of concrete, resulting in an enhancement of its freeze-thaw resistance. Besides, there is need to explore the potential synergistic effects of several chemical admixtures, with the aim of achieving improved transport properties of HVFA composites without compromising early-age strength.

Research Findings

1. Insufficient Hydration of Fly Ash

Microscopic examination by different modes (BSE, SEI, and WDS) of electron probe micro-analyzer (EPMA) was conducted to shed light on the hydration behavior of the representative HVFA mortar (Figure 1). From the obtained images, it is evident that many of the fly ash spheres remain spherical, suggesting the low hydration degree of the fly ash particles in HVFA mortars. This is the main reason for the low early-age strength of HVFA concrete.

2. Addition of GO into HVFA Concretes

Through our research, admixing GO (at 0.01%, 0.05%, or 0.1% by weight of binder) in an HVFA concrete (60% cement replacement by Class C fly ash) can significantly improve its 28-day compressive strength, abrasion resistance, and coefficient of friction. However, the decrease in microhardness value (Figure 2)

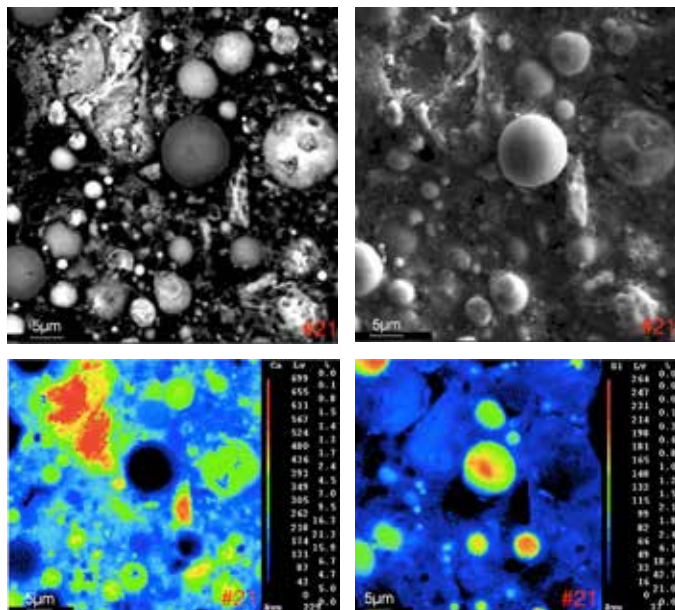


Figure 1. BSE, SEI, and WDS micrographs of HVFA mortar.

due to addition of GO in HVFA mortar may be attributed to an increase in the content and orientation arrangement of $\text{Ca}(\text{OH})_2$ crystal, which merits further investigation.

3. Addition of Chemical Admixtures

The second hurdle that limits the implementation of HVFA concrete in the field is the reduced resistance to freezing-thawing cycles and salt scaling in cold climates. As an indicator, the transport properties (sorptivity and permeability) of concrete usually greatly affect the extent of surface scaling (Liu and Hansen 2015). In this study, 10 total admixtures (five non-polymeric admixtures and five polymeric admixtures) were examined to investigate their potential synergistic effects on the transport properties of HVFA composites.

Surface free energy (SFE) calculating from water contact angle tests is used to determine the degree of surface hydrophilicity of samples (Figure 3). Besides, the porosity and pore distribution of selected HVFA mortars (Figure 4) were tested through mercury intrusion porosimeter. A conclusion can be drawn that the transport properties of HVFA mortars were mainly affected by the microstructure of mixtures, i.e., the porosity and pore size distribution, rather than their surface free energies.

Conclusion

There exist two limitations that hinder HVFA concrete's implementation in the field: (a) low early-age compressive strength due to the insufficient hydration of fly ash particles, and (b) reduced resistance to freezing-thawing cycles and salt scaling, which is generally considered related to the transport properties of concrete. The measures taken to facilitate this environmentally friendly material's use in the field include admixing nano-material (GO) and chemical admixtures into HVFA concrete. Hopefully, this study could be a part of the efforts that move forward the optimal use of this promising type of material and introduce it into mainstream use. ♦

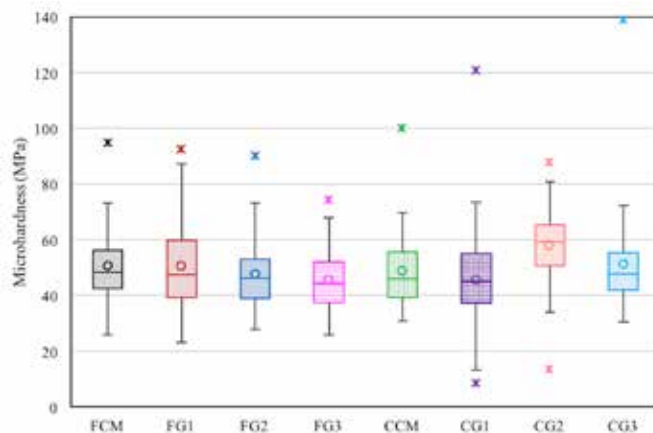


Figure 2. Microhardness of bulk paste in both HVFA mortars (FCM, FG1, FG2, FG3) and OPC mortars (CCM, CG1, CG2, CG3).

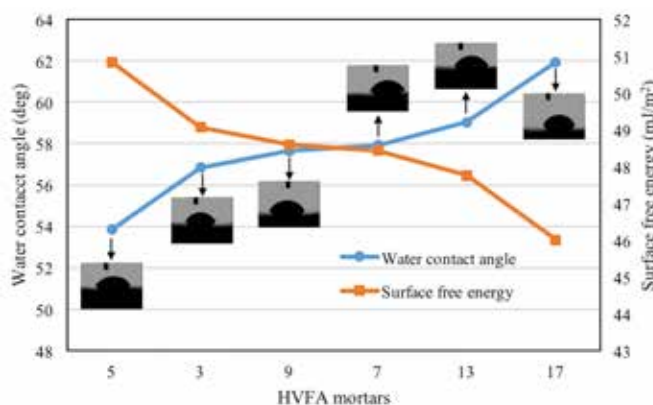


Figure 3. Water contact angle and SFE of selected HVFA mixtures.

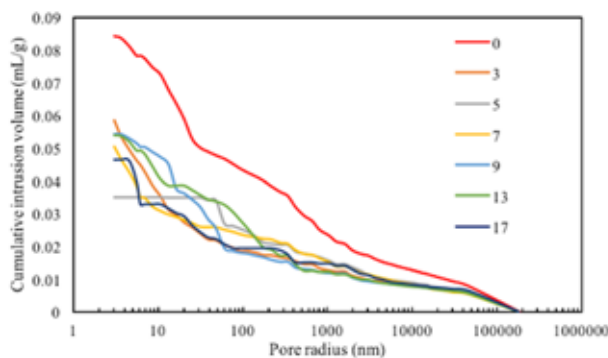


Figure 4. Cumulative pore size distribution of selected HVFA mixtures.

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Laboratory Investigation of Water Repellency Effect on Unsaturated Properties of Compacted Coal Combustion Products

By Livingstone Dumenu, Ph.D. Candidate, Interdisciplinary Infrastructure and Environmental Systems Program, University of North Carolina at Charlotte

Abstract

Recently implemented regulations by the U.S. Environmental Protection Agency and some states have seen the management of coal combustion products (CCPs) evolved from wet sloughing in a basin to dry disposal in an engineered landfill. The new regulations stipulate certain requirements, among which include sustainable and dry storing of CCPs. This research aims to beneficially reuse CCPs modified with organo-silane (OS), known as silanization, in engineered systems while introducing an alternative infiltration control system. In line with the new regulation requirement, it is important to investigate the interactions of the CCP and OS and its impact on the compaction characteristics as well as water infiltration behavior of CCPs.

Introduction

This research forms part of a recently completed project, “Water Repellency for Ash Containment and Reuse,” funded by the Environmental Research and Educational Foundation (EREF). Objectives of this project are aligned with the requirements of the EPA’s current regulations on coal ash management under subtitle D of the Resource Conservation and Recovery Act (RCRA). The requirement supports management of coal combustion products to prevent the occurrence of a catastrophic failure; protect groundwater resources; maintain the integrity of CCP receiving infrastructure through operation, maintenance, and closure criteria; and promote the responsible reuse of CCPs. The project proposed to effectively manage CCPs in engineered systems—structural fills, landfills, liners, capping systems, and embankments—and develop an alternative infiltration control system by surface modification of CCPs through silanization, which renders the CCPs water repellent. In line with the interest of the American Coal Ash Association Educational Foundation (ACAAEF) scholarship program, this research is focused on advancing the beneficial reuse and sustainable management of CCPs.

Motivation

The proposed engineered systems mostly function in unsaturated conditions but are typically designed with assumptions based on limiting conditions for saturated or dry properties. In that regard, the framework governing saturated soil mechanics is limited in satisfactorily defining the systems in unsaturated conditions (Lu and Likos 2004). It is therefore imperative to study the unsaturated properties (hydraulic and shear strength) of compacted CCPs in engineered systems. The research is motivated by the existing knowledge gap, resulting in poor understanding of the mechanics of compacted CCPs with and without silanization in unsaturated conditions, while exploring various applicable principles and theories in unsaturated soil mechanics.

Although, recent studies (Daniels and Hourani 2009; Daniels, et al. 2009a,b) suggest silanization may have wide geotechnical and geoenvironmental engineering application in beneficial reuse of CCPs, there is lack of available data to correlate the effect of salinization on engineering properties of granular materials reported in recent literature, such as reducing infiltration in treated CCPs (Daniels, et al. 2009a), increased infiltration and solute flux in naturally occurring hydrophobic soils (Nguyen, et al. 1999), and reducing shear strength of treated glass beads (Byun, et al. 2012). The research will ultimately add to the knowledge base by studying the interactions of physiochemical composition and other geotechnical engineering indexes of CCPs with water-repellent agents and their impacts on flow and shear strength of compacted CCPs.

The ultimate research goal is to investigate water-repellency effect on engineering properties of compacted CCPs. In that regard, the research objectives are to measure engineering properties that describe field-relevant parameters such as hydraulic conductivity and shear strength of compacted CCPs with and without surface modification through silanization; evaluate the unsaturated properties of the compacted CCPs by establishing

the water retention characteristics; and relate the shear strength of CCPs with index and physical properties and physiochemical compositions of CCPs.

Preliminary results characterizing geotechnical engineering properties, and elemental and mineral compositions of selected CCPs studied in the EREF-funded project, indicate that the by-products have engineering characteristics consistent with previous studies, which are further investigated (Dumenu, et al. 2017). In addition, some of the CCPs recorded (final draft of EREF project report under review) show significant electrical conductivity values consistent with high total suctions in the water-retention characteristics of the compacted CCPs, an indication of the presence of high-soluble salts.

These observations further support the need to investigate the physiochemical properties to establish correlation to relevant properties of infiltration, shear strength, and ultimately salinized CCPs. With validated data established from the laboratory experiment serving as input parameters, computational analysis will be performed to predict field-relevant performances of the engineered systems using finite-element models such as HYDRUS 2D and Geo-Studio. Finally, the water-repelling effect on the hydraulic and shear strength of CCPs—to better understand indexes that control infiltration and stability of the compacted CCPs in the engineered systems mentioned earlier—will be evaluated.

Impact

The development of alternative infiltration control will add additional economic value to CCP utilization in civil works, embankments and berms, and liner (disposal management) construction while improving the sustainability of the engineered structures in the effective management of CCPs. Ultimately, the strategic plans of ACAAEF are advanced economically and environmentally to benefit industry and the community it serves. ♦

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Predicting Performance of Fly Ash in Concrete with Automated Scanning Electron Microscopy

By Shinhyu Kang, Ph.D. Candidate, Civil Engineering, Oklahoma State University

Abstract

A new classification approach is presented that uses individual fly ash particle measurements to provide improved and more in-depth information about the properties of concrete. Automated scanning electron microscopy (ASEM) was used to examine the composition of elemental oxides for thousands of individual fly ash particles. The data were then analyzed with principal component analysis (PCA). The result shows that distinct underlying relationships exist in the elemental oxides of individual fly ash particles. Individual particle composition is useful for predicting the performance of concrete so that a more accurate prediction of performance can be made.

Essay

Fly ash has been used in the past decades as an important supplementary cementitious material. However, a useful relationship of the glass chemistry within fly ash and the subsequent performance in concrete cannot be predicted. Because of this, it is not easy to predict the performance of fly ash in concrete. In addition, past studies of the reactivity of fly ash relied on bulk characterization methods, such as X-ray fluorescence (XRF) or X-ray diffraction (XRD). While understanding the bulk chemical composition is useful, it only describes the average behavior of the system.

In practice, each coal particle independently undergoes different physical and chemical changes during the coal combustion process at the power plant. Therefore, the composition of each individual fly ash particle is the result of the type of coal and the physical and chemical processes that occurred in the power plant. Just because the average composition is similar, it does not mean that the individual particles will have similar chemistries. Thus, bulk composition alone cannot fully explain fly ash performance in concrete. A more fundamental understanding is needed for fly ash composition and for how it relates to concrete performance.

In my research, ASEM was used to examine the interrelationship among the elemental oxides for thousands of individual fly ash particles. An overview of ASEM is shown in Figure 1. Twelve fly ashes (seven Class C and five Class F) were investigated in this study and 2000 particles were analyzed for each fly ash. Therefore, 24,000 data points (12 elemental oxide compositions and diameters) were collected for each fly ash. This massive data set was then analyzed with PCA to find consistent interrelationships among oxide content in fly ash particles.

Distinct interrelationships among the oxides in fly ash particles were observed. Figure 2 describes two among six investigated interrelationships.

Figure 2(a) shows that there is a correlation between SiO_2 and $\text{Na}_2\text{O} + \text{K}_2\text{O}$. Particles with SiO_2 above 35% were observed in the particles containing either Na_2O or K_2O , while particles with lower SiO_2 content showed none of these oxides. Three more similar trends of correlation were observed in this research.

Figure 2(b) shows that there is an inverse correlation between $\text{Na}_2\text{O} + \text{K}_2\text{O}$ and $\text{P}_2\text{O}_5 + \text{SO}_3$. This shows that most of the particles that included Na_2O or K_2O did not include P_2O_5 or SO_3 . This trend indicates that the particles containing K_2O or Na_2O tend to exclude the content of $\text{P}_2\text{O}_5 + \text{SO}_3$. One more similar trend of inverse correlation was observed and used to study fly ash.

Even though just one Class C and one Class F fly ash result are shown in this essay, all 12 fly ashes show the same trend as these two fly ashes. This means that there are particles with similar chemistries contained in each fly ash investigated. However, each fly ash may contain different amounts of each type of particle. These interrelationships can give strong insight into the fundamental organization of the fly ash particles.

The interrelationships suggest that fly ash can be described as an assemblage of some groups of particles with repeating

chemistries. To classify the particles, a procedure named Particle Model was used. The Self Organizing Map (SOM) method was applied in this procedure and found nine compositionally distinct particle groups from ASEM analysis data for the 12 fly ashes. This is a significant discovery, as it suggests that fly ashes can be characterized by first finding these clusters and then determining the amount of particles in each of these clusters.

Concrete cylinder samples with 20% fly ash replacement by mass were made and compressive strength testing was performed. The nine particle clusters were used to predict the compressive strength of the concrete.

The prediction of the compressive strength change over time for the Class C or F classification has an R-squared value of 0.9381, and this improved to 0.9981 for the Particle Model. Figure 3(a) shows the comparison for predicted and actual strength gain with the type of fly ash used, and Figure 3(b) shows the predicted and actual strength for four fly ash results based on the Particle Model. The actual measured values are shown as points on the chart matching the colors of the line. The difference between the C and F curves does not capture all of the differences in performance. Since the Particle Model accounts for differences in particle composition, it can more accurately predict the compressive strength of concrete than the bulk composition of the fly ash.

This study found out that distinct underlying relationships exist in the elemental oxides of individual fly ash particles. Individual particle composition is useful for predicting the performance of concrete so that suggested modeling can be a more accurate method to predict the compressive strength of the concrete. This finding is an important step to develop a more general classification of fly ash based on the individual particle makeup that allows a priori predictions about the performance of the fly ash in concrete.

Acknowledgments

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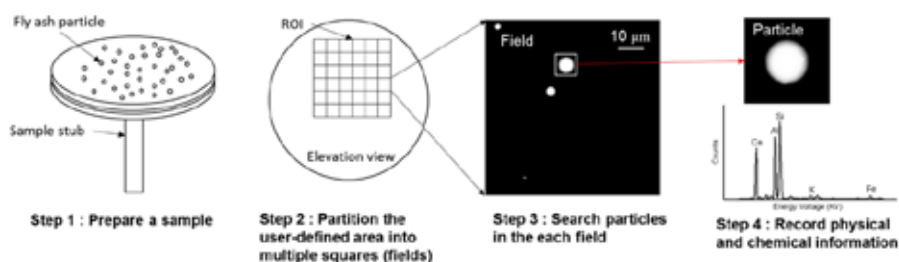


Figure 1. Schematic process of ASEM method.

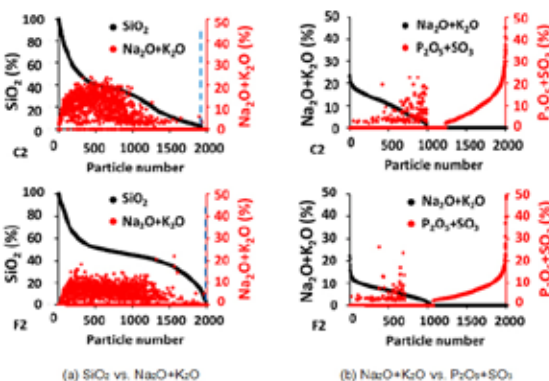


Figure 2. Verification of interrelationships observed using PCA among elemental oxides.

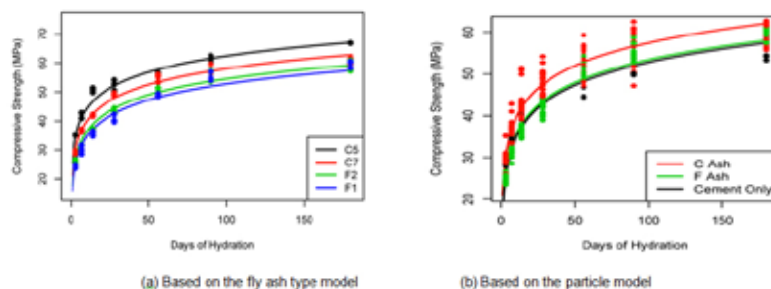


Figure 3. Predicted versus actual performances of compressive strength.

Additives in Concrete Through Novel Particle Characterization," Sponsor: National Science Foundation. Several new particle analysis techniques will be used to study the 3D chemistry and reactive phases within fly ash and slag. The focus of the work is to determine the impact of these different chemical phases on the performance of concrete. Funding: \$400,000 over 5 years. ♦

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Effect of Superabsorbent Polymers as an Admixture on Durability Properties of Concrete Containing Fly Ash

By Siamak Riyazi, Ph.D. Candidate, Civil Engineering, University of Missouri-Kansas City

Abstract

Super absorbent polymers (SAPs) are novel multipurpose materials in concrete technology. This study investigates the potential for using SAPs as a mechanism for physical air entrainment in fly ash (FA) concrete. The quality of the air void system is investigated using a high-resolution flatbed scanner and image analysis. Also, the effects of different particle size and conditions of SAP in FA concrete are studied. It is believed that SAP will improve the freeze and thaw durability of FA concrete.

Introduction

Concrete is the most handled man-made material on earth, with three tons produced per person per year. Fly ash is one of the most important supplementary cementitious materials and is used in the majority of concrete structures, especially in the United States. FA is produced during combustion in coal-fueled power plants.

Freeze and thaw deterioration is the greatest threat for concrete in cold climates. Concrete is air entrained to improve durability and ultimately service life. Traditionally, air voids are made in concrete using chemical air-entraining agents (AEAs). These surfactants stabilize the air bubbles created during concrete mixing and prevent small bubbles from coalescing and escaping. Air pollution regulations and requirements have reduced the quality and availability of FA, further exasperated by low-cost natural gas and renewable energy requirements. Coal-fueled power plants are injecting various air pollution-reducing agents (active carbon and ammonia), which end up in the FA. Carbon, especially, has a high affinity to absorb AEA surfactants in fresh concrete, leading to a reduction in the amount available to create stable air bubbles in concrete.

The decreasing number of FA suppliers and market-variable composition and characteristics of FA have made it difficult

for the concrete industry to produce FA concrete with consistent properties. Also, the varying amounts of activated carbon in FA from different manufacturers make it difficult to produce air-entrained FA concrete with the same air systems. It is well discussed that portland cement concrete pavements use high amounts of concrete, and substituting fly ash provides significant economic benefits. Furthermore, promising technical effects of FA in concrete warrant further investigation to mitigate undesirable effects of high-carbon FA in air-entrained concrete. A promising method to have stable air voids in FA concrete is physical air entrainment using materials that produce desirable voids in cement paste. Concrete durability can be enhanced with predefined size and spacing of air voids.

In 2001, Jensen and Hansen found that a potentially cost-effective method to have a predefined size and spacing of air voids is to use super absorbent polymers (SAPs). SAPs have initially been used in sanitary and convenience products. They are cross-linked hydrophilic networks of acrylic acid and acrylamide, neutralized by alkali hydroxide that can absorb a large quantity of specific substances from the surroundings, resulting in formation of hydrogel. SAP has the ability to retain the liquid and not become dissolved after swelling. Most of the water content in SAP is used in the hydration process in the first 48 hours after mixing, which causes the SAP to shrink and leaves an air void. Although it is commonly believed that using AEAs and SAPs gives the same results regarding air voids in concrete matrix, air voids in cement paste resulting from using SAPs remain more stable during consolidation and transportation.

Air voids in concrete containing AEAs frequently are not sufficiently stable to tolerate transportation, compacting, and existence of high-carbon FA. In contrast, the pore system in concrete enhanced with SAP seems to remain stable regardless

of concrete consistency, the presence of surfactants, or of the method of placement and compacting. Few studies have been conducted on the use of SAP to enhance the durability-related properties of FA concrete of normal strength made with type I/II cements. For regular-strength concrete, the effects of SAP in FA concrete mixture regarding compressive strength and durability properties will be investigated in this study, as well as the effects of the size of SAP particles on FA concrete durability against freeze/thaw action. Another objective of this study is to use a relatively cheap SAP in FA concrete.

Background

There is no detailed research on the effect of SAP particle size distribution on the durability properties of concrete containing FA. SAPs are novel materials about which RILEM (the International Union of Laboratories and Experts in Construction Materials, Systems, and Structures) in 2007 formed Technical Committee 225-SAP, "Application of Superabsorbent Polymers in Concrete Construction." The American Concrete Institute does not yet have a committee in this area. Particularly for application to mitigate freeze and thawing deterioration, SAPs are a promising material that warrant further investigation.

Method

This research will study the effect of SAPs with different particle size distributions on FA concrete durability. Four mixtures will be produced with 0.125% dry/saturated SAP by weight of cement using two different fine/coarse particle size distributions. Previous research has shown a dosage of 0.125% by weight of cement produces a similar volume of air to traditional AEAs. Figure 1 shows the air voids of a cement mortar cube containing 0.125% pre-saturated SAP in previous research. The baseline control mixture will be produced with a synthetic AEA and 25% replacement of cement with good-quality FA. A secondary control will contain activated carbon with no SAP to simulate a problematic mixture. Other than the baseline control, activated carbon will be used at 4% in all mixtures to simulate FA with high carbon content, which is known to eliminate the air system. Mixture proportions will be based on standard Missouri Department of Transportation concrete mix design for pavement. Testing will include compressive strength (ASTM C39), absorption (ASTM C1585), and freeze-thaw durability (ASTM C666). The porosity will be studied by scanning electron microscopy and optical microscopy if needed. The combination of all characteristics will give a general overview of the effects of SAPs on durability and other properties of concern. All tests will be performed in triplicate. ♦

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Figure 1. Scanned image for air voids analyzing cement mortar cube section containing 0.125% pre-saturated SAP.

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Coal Combustion and Gasification Products, a peer-reviewed journal designed specifically to communicate coal ash research and emerging new technologies, is issuing a **call for papers**.

CCGP is an international on-line journal that encompasses the science and technology of the production, sustainable utilization, and environmentally sound handling of the by-products of coal combustion and gasification. This includes fly ash, bottom ash, boiler slag, gasification residue, and by-products from coal-fuel blends, flue-gas desulfurization products, and related materials.

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2018 Workshop on Current Issues in Ponded CCPs

Following are abstracts from the presentations delivered at the Workshop on Current Issues in Ponded CCPs, held March 20-21, 2018, in Richmond, Virginia. PowerPoint slides from many of these same presentations can be found at the World of Coal Ash website.

TVA CCR Pond Closure Processes and Designs

Nick McClung, P.E., The Tennessee Valley Authority

Shane Harris, PMP, The Tennessee Valley Authority

The Tennessee Valley Authority (TVA) has been in the process of converting coal combustion residual (CCR) facilities from wet to dry operations since 2009. As part of this process, TVA began building dewatering facilities for fly ash, gypsum, and bottom ash and planning closures of wet impoundments and building new solid waste landfills to manage the dry CCRs. Since 2009, TVA has closed or is in the process of closing 11 CCR impoundments.

Over the last nine years, TVA has learned that closing a CCR facility is a unique process, and each closing comes with its own challenges. This presentation discusses TVA's process for planning impoundment closures and the design considerations that are evaluated during the process. It also discusses the importance of quality assurance and instrumentation as part of the closure process.

The Design and Monitoring of Geotextile Tube Use in CCR Impoundment Closure

Christopher M. Gee, Dominion Energy

Scott Sheridan, Geosyntec Consultants

Most coal combustion residual (CCR) impoundments require dewatering prior to closure. Many dewatering methods in use are time consuming or expensive. Additionally, because CCR, or coal ash, is a non-traditional geotechnical material that has only recently begun being extensively studied, gaps remain in the knowledge base as to the types of dewatering technologies that are most effective. Geotextile tubes are a tried-and-true environmental dewatering method considered an attractive option because they can be relatively inexpensive, dewater slurries quickly, and fully contain the dewatered waste.

A case history of the construction of a geotextile tube wall in an ash pond at a confidential site for a large mid-Atlantic

utility is presented. The geotextile tubes were stacked in two layers and formed an approximately 11 ft. high, 2400 ft. long wall constructed mostly in a 3-2 pyramid structure. The wall separated the ash pond into two areas: a pool, which continued to serve as an operations area to receive sluiced coal ash, and an area where construction of final closure grades was to be started. Coal ash from the pool area was dredged and pumped into the geotextile tubes, reducing the amount of coal ash that would otherwise have needed to be stabilized in place during the final closure. The wall also served as a buttress to improve slope stability during interim construction.

Geotechnical slope stability and settlement analyses were performed during the engineering design phase. To evaluate the effectiveness of dewatering coal ash using geotextile tubes, ash samples were collected from the site and sent to a laboratory for dewatering testing to determine polymer type and dosage. Based on design recommendations, piezometers were installed underneath the geotextile tubes to monitor porewater dissipation in the ash. A comprehensive monitoring program consisting of instrumentation, field observations, construction sequence evaluation, and other monitoring methods was conducted to maintain safe and effective work.

Seismic Design Recommendations: Liquefaction of Ponded Ash, Field and Laboratory Characterization, and Recommendations to Evaluate Embankment Stability for Seismic Loads

Dr. William Wolfe, P.E., The Ohio State University

Dr. Robert C. Bachus, P.E., D.GE, Geosyntec Consultants

The potential for dynamic liquefaction of ponded fly ash can be determined by analyzing field- and/or laboratory-obtained material properties of the ash in the context of the appropriate site-specific seismic ground motions. If the results of these calculations indicate a potential for liquefaction of the ash, the final closure grades and embankment stability may be adversely impacted. In this presentation, the laboratory characterization of ponded ash is introduced, followed by a discussion of procedures and results for laboratory cyclic triaxial testing of samples recovered from several ash ponds. In addition, techniques for field characterization of ponded ash and results from these field tests are discussed. Finally,

the presentation describes how these results can be used to establish seismic strength relationships for ponded ash and to assess the potential for dynamic liquefaction given site-specific ground motions. Depending on the geometry of the ash pond and the potential for liquefaction of the ponded ash, the final cover grading and the containment embankment/dike stability may be adversely impacted. Recommendations are provided regarding the evaluation of embankment stability for the design seismic loading.

Closure in Place: Regulatory Design Issues and Impacts

Kula Kulasingam, Ph.D., P.E., AECOM

John Bove, P.E., AECOM

Safe, effective, and environmentally sound closure of CCR impoundments poses key challenges for power generation utilities across the country. Comprehensive federal regulations were promulgated in April 2015 that establish siting, design, closure, beneficiation, groundwater, and corrective action criteria. Several states have developed their own regulations related to closure of ash basins. Closure impacts the regulatory processes for surface water, dam safety, and flood management. In addition to regulatory compliance, recent legal and legislative actions in Southeastern states have significantly altered the process of selecting and implementing closure.

Alternatives to close ash impoundments under current regulations include closure in place, closure by removal with landfilling or beneficiation, or a combination of these alternatives known as “hybrid” closure. Selection of the preferred alternative is generally based upon regulatory compliance, safety, cost, schedule, and other drivers. Owners of ash impoundments were required to post their selected closure method on a public website after October 2016. A general overview of the publicly identified closure method for ash impoundments located in the Southeast is provided and broken out in this presentation by size and CCR volume of the ash impoundment.

Under federal CCR regulations, the selection of a closure method is left to the owner. Recent legislation in Virginia, as well as recent judicial decisions in several states, are driving the selection process to include an evaluation of all feasible closure alternatives—not just the owner-selected alternative. The selection process must include more detailed evaluation of closure impacts, including safety, community impacts, transportation options, long-term durability of closure systems, long-term groundwater impacts, and opportunities for remedial measures.

This presentation addresses these impacts as well as the engineering challenges associated with final cover design, such as slope stability, settlement, wastewater treatment, dewatering, and closure phasing. In particular, for sites where closure in place is the selected option, key regulatory and state-of-practice-based design considerations are presented. A robust design framework will be needed to demonstrate the long-term performance of closure in place and receive regulatory, legal, and stakeholder acceptance.

Pond Closures with Ash Pre-Drainage Dewatering—From Geotechnical Investigation to Practical Field Considerations

Paul C. Schmall, Ph.D., P.E., Moretrench American Corporation

Andrew T. North, P.E., Golder Associates

Coal combustion residual (CCR) impoundment closures that involve removal, consolidation, and/or stacking of CCR material result in many challenging construction activities. These construction challenges include draining and dewatering practices, stability of the CCR surface for operations, construction of structural barriers, short- and long-term slope stability, and material behaviors during construction when subjected to equipment vibration. It is essential to have a good geotechnical investigation, historical information, and an understanding of the unique and difficult behaviors of fly ash for development of an optimal closure plan and a practical approach to construction.

Over the past several years, significant improvements have been made in practically achievable geotechnical investigation methods, pilot dewatering tests in ash, and correlating those observations to dewatering performance and ash stability. Real-time monitoring of conditions has promoted safe and efficient work practices during construction when used in conjunction with shallow and deep dewatering systems.

This paper discusses the current state of pond closure practice, including such aspects as geotechnical investigation, monitoring, correlation of early field observations to the dewaterability and stability of the ash, site water management, and sequencing of the work. Examples of current and recently completed projects illustrate what can be achieved with respect to fly ash pond closure with the assistance of pre-drainage dewatering techniques.

Response of Ash to Dewatering: Correlating Geotechnical Investigation to Performance

Paul C. Schmall, Ph.D., P.E., Moretrench American Corporation

The hybrid closure concept appears to be widely accepted as a highly beneficial approach, both technically and cost effectively. The typical hybrid closure involves a number of difficult construction elements, including dewatering and excavation of wet ash, stacking ash, and in some cases installation of geostructural barriers to permit both excavation and stacking to occur within a limited footprint. These construction elements force us to address a number of significant geotechnical considerations. Drainability and dewaterability of the ash are obvious factors, but so too are slope stability, shear strength at various and changeable degrees of saturation and disturbance, and “stable crust thickness.”

Despite the experience gained on many sites to date, the geotechnical behavior of ash remains highly uncertain; each pond appears to have a unique personality. Nevertheless, significant knowledge has been developed in practically achievable geotechnical investigation methods in ash, correlating those observations to material behavior

(particularly dewaterability), and real-time monitoring of conditions.

This paper discusses the current state of practice in geotechnical investigation and correlation of that information to the behavior of the ash, particularly as it pertains to dewaterability and stability. Pilot testing or early exploratory in-place testing has been of great benefit where performed. Practical examples of current and recently completed projects illustrate the relationship among geotechnical investigation, ash stability, and the performance of the dewatering system(s).

The Recovery of Fly Ash from Ponds and Landfills: Specs and Techs

Tom Robl, Ph.D., University of Kentucky Center for Applied Energy Research

The closing of coal-fueled power plants along with changes in the regulatory environment has brought about interest in the recovery of fly ash from ponds and landfills. Over the past three years, the Electric Power Research Institute has fostered investigations into the available recovery technology, as well as the applicability of the current set of standards to the recovered materials.

A plethora of technologies are found to be available for the recovery of ash. These span from high-capacity auto thermal combustion technologies that can recover high-LOI ponded or landfilled ash to simple screening technologies combined with thermal driers. It is presumed the choices would be driven by variables that include the quality of the ash, market conditions, available capital, and regulatory considerations.

Quality standards for the use of fly ash in construction materials, primarily concrete, are found in North America, Europe, and Asia. In the United States the ASTM C618 standard applies. Europe follows the EN 450 standard, which uses a somewhat different approach. The largest difference between the two standards is in the measurement of strength index (SI), a direct calculation of performance. ASTM SI measurements are based on constant flow, which assesses the packing and rheologic contributions of the fly ash to the test mortars. EN 450 SI is based on constant water content, which assesses the pozzolanic activity of the ash.

Class F ash recovered from old dredge cells is compared with fresh, high-quality Class F commercial ash. The ash samples have similar particle size distributions. However, the ashes recovered from the landfill contain plant and other debris, primarily in the plus-50 mesh size. Both European and U.S. methods are used to measure SI over a period of 90 days. The performance of both ashes is essentially identical, easily meeting the requirements of the standards. The conversion of $\text{Ca}(\text{OH})_2$ of the ashes is also directly measured by thermal gravimetric analysis, with the landfilled ashes showing somewhat higher conversion. The data to date indicates that, with minimal processing to remove coarse debris, Class F ash recovered from ponds and landfills that meet national standards should perform well in construction applications.

Sampling, Testing, and Instrumentation of Ponded CCR Impoundments: Available Techniques, Sampling/Testing Needs for Safe Designs, and Planning for Potential Future Harvesting

Greg Hebel, Golder and Associates
Ben Gallagher, Southern Company

This presentation focuses on available techniques and case studies for sampling, testing, and instrumentation monitoring of ponded CCR impoundments. The presentation covers planning and techniques for exploration programs for geotechnical investigations, beneficial use harvesting investigations, and CCR closure and post-closure instrumentation monitoring programs. The pros and cons of various techniques are covered, with focused examples using CPT, drilling, VST, VW piezometers, inclinometers, cyclic and static laboratory testing, and other data. Case studies discuss the amount and types of data that are needed to feed robust designs focused on safety, as well as potential risks such as static and dynamic liquefaction, groundwater controls, and fill and excavation slope stability. The presentation also focuses on planning and data needs to evaluate potential future CCR harvesting for beneficial use, as well as the combination of geotechnical and beneficial use data required to make more complete assessments of CCR units.

Status of Groundwater Monitoring and Corrective Action Under the CCR Rule

James R. Roewer, Utility Solid Waste Activities Group
Kathleen D. Regan, Amec Foster Wheeler E&IS (Wood)
Alison L. Dunn, Amec Foster Wheeler E&IS (Wood)

The first portion of the presentation consists of a regulatory overview by the Executive Director of Utility Solid Waste Activities Group (USWAG) and includes coverage of existing regulatory requirements, deadlines, and timelines in the CCR Rule, as well as an analysis of potential revisions to the rule proposed in response to USWAG's rulemaking petition to the U.S. EPA. The current status of individual states' CCR permit programs is also reviewed. The second portion, using recent real-life examples, reviews the complex pathway, decision points, and triggers involved in moving through the groundwater monitoring and corrective action requirements of the CCR Rule.

The rule establishes a framework for groundwater actions that includes the following steps (as applicable): establishing a groundwater monitoring network and program; detection monitoring; assessment monitoring; establishing groundwater protection standards; groundwater characterization to support remedy selection; assessment of corrective measures; selection of remedy; implementation of the corrective action program; and completion of remedy. However, now that the process is under way, the self-implementing nature of the rule has led to different interpretations of requirements, and some unforeseen consequences are coming to light. Further complicating matters is the potential to move enforcement of the rule to state agencies according to the WIIN Act. EPA's intent to make modifications to the rule in phases over the next year or

two could significantly alter the framework for groundwater corrective action.

Specific areas that are currently hot topics in the process are the application of statistics to groundwater monitoring data and determination of alternative sources for constituents detected above background or above the MCL. Real-life examples of how these and other steps in the rule are being interpreted and navigated at different types of CCR sites are presented. A major paradox associated with corrective action of groundwater impacted by CCR is also reviewed—i.e., with some notable exceptions, the constituents that trigger and drive corrective action (the Appendix IV constituents) are generally amenable to attenuation in groundwater under natural conditions, across relatively short distances. Furthermore, under the CCR Rule, groundwater corrective action can be triggered by relatively low concentrations of these constituents—so low that they cannot be efficiently cleaned up—and probably would not be actively remediated in other regulatory settings. If risk-based options are not ultimately adopted in the modified rule, the art will be in selecting and designing remedies that can cost-effectively address relatively low levels of constituents at the waste unit boundaries.

Groundwater Quality Changes After Closure in Place: 25 Years of Observations

Bruce Hensel, Electric Power Research Institute
Stuart Cravens, O'Brien and Gere

Groundwater quality changes can be expected when a pond is closed in place. The type and degree of changes will depend on factors such as the type of cap, hydrogeology, and whether or not groundwater is intersecting. Case examples, from a few years to more than 25 years, are presented for a variety of ponds that have undergone in-place closure in varied hydrogeologic environments with a range of water quality characteristics. Drivers for observed change, or lack of change, are presented for each facility. In addition, examples of groundwater model prediction results for recent closure plans of impoundments using modeled caps are presented.

Utility-Specific Groundwater Monitoring Strategies and Requirements: CCR Monitoring Day to Day—What Do Utilities Care About?

Harold D. Register, Jr., P.E., Consumers Energy
Eric Wallis, JD, P.G., Southern Company
Jason Williams, P.G., Dominion Energy

The U.S. EPA promulgated minimum standards for owners and operators of landfills and surface impoundments that manage coal combustion residuals (CCRs) under Subtitle D of the Resource Conservation and Recovery Act (RCRA). Compliance with groundwater monitoring and corrective action represent one of the most complex elements of the rule based on the staggered compliance schedule intertwined with inferences of how/when operations of certain CCR units can be impacted.

The utility industry cares about defensibility of the data collected through groundwater monitoring programs. Additionally, there is substantial effort spent ensuring the

integrity of the data analysis/conclusions and that the technical competency of the analysis is completed by competent practitioners. The groundwater monitoring programs should reliably demonstrate protection of human health and the environment and that the public can be assured that the standards for closure, design, operation, and long-term stewardship are executed in good faith and meet all applicable regulations.

The utility industry is primarily planning for the technical challenges of maintaining groundwater monitoring programs and developing strategies for managing short-term and long-term groundwater impacts. These strategies are also under evaluation in terms of closure strategies and potential corrective action remedies. Finally, the utility industry is planning on managing a changing regulatory environment. Significant changes in regulations that impact short-term and long-term planning include states establishing CCR permitting programs with EPA review and approval, as well as anticipated changes in the underlying CCR RCRA rule regarding groundwater monitoring and remediation.

Three different utility company perspectives are presented with respect to the important and critical day-to-day groundwater management issues. These presentations include utility perspectives regarding: (1) their priorities with respect to the implementation of the groundwater monitoring requirements, and (2) planning for the future, both near-term and long-term. These presentations include initial impression of results, potential operational impacts, challenges faced, lessons learned, and strategic planning for potential future use.

Current Overview of Groundwater Remediation Options for CCR Units

Christopher A. Robb, P.E., Geosyntec Consultants
Herwig Goldemund, Ph.D., Geosyntec Consultants

Groundwater below many basins that have been used to store coal combustion residuals (CCRs) may have concentrations of certain inorganic constituents in excess of applicable regulatory standards. If a link between a CCR unit and an inorganic groundwater exceedance has been established, stakeholders may be faced with the need to evaluate groundwater remedial alternatives to address these impacts. This presentation conceptually discusses potentially applicable remedial approaches, including:

- Monitored natural attenuation (MNA)
- Hydraulic control using ex-situ and in-situ methods
- Permeable reactive barriers
- Slurry walls
- In-situ stabilization/solidification (ISS)
- Oxidation-reduction (redox) altering approaches
- Biogeochemical injections

Each of these potentially applicable groundwater remedial approaches is presented in terms of its best fit for corrective action and closure of CCR units. Additionally, this presentation explores real-world experiences and applications relevant for implementation of the groundwater remediation technologies at CCR units.

ASH Classics

Use of Ash Tested in Road Construction Projects

"Ash Classics" is a recurring feature of ASH at Work that examines the early years of the American Coal Ash Association and its predecessor National Ash Association (NAA), focusing on issues and events that were part of the beneficial use industry's defining years.

Coal combustion products are now widely used in highway construction—in concrete, road base, flowable fill, embankments, and other beneficial applications. This 1978 issue of ASH at Work highlights the testing of fly ash in two Midwestern DOT road projects.

ASH AT WORK

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RCRA Timetable

The EPA's implementation schedule to manage and control hazardous wastes, including coal by-products, has been set. Ash producers and users have until March 16 to comment on the proposed regs.

Under the court approved timetable the regs are to be finalized by the Federal agency on Dec. 31, 1979 and will be become effective July 1, 1980.

Like the air pollution control standards, the harsh "cradle to the grave regs" appear to be "billion dollar criteria based on a 25-cent data base."

The electric utility industry has enlisted the support and expertise of the National Ash Association to help draft its response and recommendations. Director John H. Faber is working closely with the Utility Solid Waste Activities Group (USWAG) on the formulation of a reply.

Fly ash, bottom ash, boiler slag, scrubber sludge have been placed in a "special" category along with cement kiln dust, mine refuse, gas and oil drilling muds, and production brines.

A footnote in regs indicate it is not known how much of the total quantity of coal ash "is, in fact, hazardous material."

The proposed new EPA guidelines are recorded in the Federal Register dated December 18, 1978. Get your copy today, review it, and be prepared to act or react.

Environmental impact needs to be balanced against economic considerations in establishing overall priorities. The answer is not in the courts, but in the enactment of practical, realistic, and attainable rules.

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71 Papers Selected

Atlanta Symposium Topics Are Set

WASHINGTON, D.C.—Seventy-one presentations are incorporated in the program for the Fifth International Ash Utilization Symposium to be held in Atlanta, GA, on February 25-27 at the Atlanta Hilton.

The schedule includes a Sunday program of special interest to the cement industry, a general session on Monday morning and two concurrent programs that afternoon, three separate all-day sessions on Tuesday.

Two luncheon speakers will deliver messages on environmental and legal guidelines.

Co-Chairman John H. Faber, who is coordinating the program, noted 19 papers have been accepted from foreign ash technologists in keeping with the international concept of the symposium.

Faber disclosed Atlanta Hilton officials would like to have room reservations by February 4. Overall attendance is expected to reach 450-500.

The co-chairman for the two-day event is William T. Wertman of the Morgantown Energy Research Center. He and NAA President James E. Davis, vice president-operations for Allegheny Power System, will participate in opening day ceremonies.

Session topics and chairmen, as listed on the enclosed program, are as follows: Session B—"Classification, Minerals Recovery, Product Development," Ronald E. Morrison, American Electric Service Corporation; Session C—"Environment, Ash Collection & Storage," Robert J. Collins, Valley Forge Laboratories; Session D—"Fly Ash in Cement and Concrete," Robert J. Morrison, Western Ash Company; Session E—"Geotechnical Applications-Roads and Structural Fills," William E. Morton, Highway Materials, Inc.; Session F—"Grouting and Land Reclamation," John P. Capp, U.S. Bureau of Mines.

The luncheons will feature Ms. Penelope Hansen of the Environmental Protection Agency who will discuss "Guidelines For Government Procurement of Waste By-Products" and

George P. Graves of American Alloy Steel, Inc. whose topic is "Ash Liability in Cement Replacement."

Leon Trief of Belgium will review his cement making process incorporating high volumes of fly ash for representatives of cement industry at 5 p.m. on Sunday, Feb. 25. His remarks are titled "The Development of Trief Cement."

International presenters include delegates from the United Kingdom, Australia, Canada, India, Belgium, Saskatchewan, Yugoslavia, Romania, and the U.S.S.R. Co-Chairman Faber added 25 percent of the papers accepted had foreign authors.

(See ATLANTA, Page 2)

Short Course Set For LSU Campus in April

Plans are being finalized for staging a three-day Ash Short Course at Louisiana State University in Baton Rouge, La. on April 23-25, 1979.

The format will follow the pattern of similar conferences held at West Virginia University, Texas A & M University, and Arizona State University and cover a wide range of subjects on power plant ash and its uses.

Attendance will be limited to 100 applicants. Coordinator Ara Arman, chairman of the Department of Civil Engineering at LSU, said the program will be of special interest to utility personnel, ash marketing agencies, construction, and drilling interests.

The conference is being co-sponsored by the National Ash Association, the Civil Engineering Departments at WVU and LSU.



New basemix goes down

Ohio DOT Tests Ash/Fluidized Bed Basemix

BELLAIRE, OH—An experimental road base containing a fly ash/fluidized bed material mix was recently installed on a segment of Route 3 near here by the Ohio Department of Transportation.

The project involves the placement of three different six-inch formulations. The total length of the demonstration is 190 feet.

The mix design incorporated the use of natural Ohio aggregates, spent bed residues from fluidized units in Alliance and at Battelle Laboratories in Columbus, and ash from Ohio Edison's Berger Power Station. One section had 40% aggregate and 30% each of residue and ash and the other two used a blend of 75% aggregate, 15% bed material, and 10% ash.

The mixing was done in a conventional pugmill, was placed with an asphalt paver or motor grader, and compacted with steel-wheeled and vibratory rollers. A bituminous overlay was put down over the basemixes. The work was done by crews from John Tonkovich & Son of Shadyside.

Field results favored the use of a spreader box behind a dump truck with final placement by the grader.

Monitoring will be done by the ODOT and Valley Forge Laboratories of Devon, PA, over the next 12 months. The average daily traffic volume over the test section will also be recorded, particularly its use by coal hauling trucks.

ODOT interest in the use of coal by-products in highway construction stemmed from earlier conferences with planning and staff personnel in Columbus. The first of these sessions, held under the auspices of the National Ash Association, was at Columbus in 1976.

The sessions were coordinated by R. E. Catlin, chief engineer of Planning &

Design for ODOT and covered a wide range of subjects. Staff members from the Bureau of Construction, Bureau of Maintenance, Bureau of Tests, Bureau of Bridges, Bureau of Location and Design, Bureau of Research and Development participated in the conferences.

The ODOT has initiated two other projects as a result of these meetings. The first was the use of a fly ash embankment to support a bikeway in the Dayton area.

Inclement weather has halted work on the placement of a fly ash embankment around concrete bridge abutments at the intersection of State Routes 7 and 148 near Powhattan Point in Belmont County.

Crews from Tonkovich & Son have already placed 2,245.35 tons of fly ash at one end of the structure. The ash is coming from Ohio Edison's nearby Berger Station.

Atlanta Symposium . . .

(Continued from Page 1)

Registration fee for the symposium is \$80 which covers pre-prints of the technical papers, a Sunday reception, continental breakfasts, two lunches, and all coffee breaks.

3 Utilities, Nine Others Join NAA

Twelve firms, including three electric utilities, have been accepted as new members in the National Ash Association, according to Executive Director John H. Faber.

Utility voting privileges have been granted to Pennsylvania Power & Light Co. of Allentown, PA, Iowa Public Service Co. of Sioux, IA, and Consumers Power Co. of Jackson, MI.

Other new affiliates are Ash Management Systems, Inc. of Atlanta, GA, Industrial Technology, Inc. of New Haven, IN, Transit Mixed Concrete Co. of Azusa, CA, Kanawha Valley Fly Ash Co., Charleston, WV.

Environmental Site Developers, Inc. of Springfield, IL, Del Val, Inc. of Portland, OR, Stablex Corporation of Radnor, PA, Thomas Foundries, Inc. of Birmingham, AL, and Trinity Materials, Inc. of Hattiesburg, MS.

Designated board members from the ash producing utilities include C. E. Snyder, Manager—Fuel Purchasing & Transportation for PP & L; Russ Christiansen, Production Manager, Iowa Public Service; and R. C. Youngdahl, Consumers' executive vice president.

NAA President James E. Davis has named two in-house fact finding committees to address subjects of increasing importance in the day-to-day operation of the organization—membership and program staffing.

"The complexity of environmental concerns now facing the industry make it imperative that we be prepared to offer our membership greater technology and guidance," Davis noted.

Ronald E. Morrison of American Electric Power Service Corporation heads the group on "Membership and Top Management Liaison."

Arthur R. Stefanski of Niagara Mohawk Power Corporation is examining the NAA's "Program Budget and Staffing." A sub-committee in this area is working on the development of a manual on "Ash Utilization." Alex L. Huhmann of Public Service of New Jersey is directing this program.



BIG JOHN SAYS:

A full-scale ash management program will soon be mandated for all electric utilities operating coal-fired generating facilities.

Get The Facts . . . Join the N.A.A.!

ASU Short Course Told Fly Ash Eases Cement Shortage

TEMPE, AZ—Participants in the Ash Short Course held here on the campus of Arizona State University in November were advised the use of fly ash has enabled the oil industry to maintain drilling schedule during the current cement shortage in the Southwest.

The three-day conference attracted 94 persons. Topics discussed covered a wide range of subjects from production and availability to specific construction applications.

Dwight Smith, Cementing Coordinator for Halliburton Services, said the use of ash in cement grout mixes has made it possible to extend dwindling supplies of cement. The shortage began about 18 months ago and no let up is in sight.

"The increase in drilling activity to meet the nation's growing energy demands has been greatly assisted by the use of power plant ash," he stated.

Halliburton uses fly ash on a world-wide basis in cementing mix designs created for oil and gas industry. In some instances, deep wells have been cemented with mixtures of fly ash and hydrated lime together with an activator. The latter functions as a catalyst for setting in the annulus around the casing.

Other speakers on the program utilized case histories to document the fact that power plant ashes can be applied in a variety of uses and yield equal or better performance than traditional materials at an economical cost.

Data was also presented to indicate increased amounts of ash will be available in the Southwest by the mid-1980's as projected new coal-fired electric generating stations come on stream.

Utility producers were advised new EPA regulations will require the ash industry to prove they can develop, utilize, and manage environmentally acceptable systems for the storage and applications of these coal by-products.

Dr. Roger Seals, program coordinator and professor of Civil Engineering at West Virginia University, stated "a greater effort is needed to assist in developing comprehensive evaluation techniques which will allow us to predict rather than measure behavior."

The Ash Short Course was co-sponsored by WVU, Arizona State University, Engineers Testing Laboratories, Inc., and the National Ash Association.

ETL Vice President John C. Rosner directed the day-to-day activities and coordinated the registration.

Morrison Urges Stronger NAA Financial Support

Stronger financial support for the National Ash Association was one of the major recommendations of Robert J. Morrison, president of Western Ash Company, during a panel discussion on the subject of "What is Needed to Further Ash Utilization" at the Phoenix Ash Short Course.

The president of the Arizona based firm noted "the NAA has done very well on a very limited budget" and added "distributors like Western should pay at least 10¢ per ton."

Morrison cited the need for expanded testing and research programs, institutional advertising, and media promotions.

He also urged utility ash producers to recognize the need for technical and professional sales efforts for coal by-products.

NAA Consultant Al Babcock stressed the need for the documentation of ash applications and the creation of a world-wide ash technology data center at the association's Washington offices.



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ASU class in session

Iowa DOT Project Eyes Fly Ash as Cement Replacement

BLENCOE, IA—The Iowa Department of Transportation is testing fly ash as an economical replacement for up to 15 percent of the cement in a six-inch concrete pavement on a five-mile segment of a county road near this Monona County community.

The DOT is monitoring the project to aid in the development of a specification permitting fly ash as an approved supplement. Twenty-eight day, six-month, and 18-month strengths will be noted and the post construction evaluation will continue for five years.

Chuck Huisman, head of Office of Materials, says projects are planned in other sections of state to further test the use of ash in highway construction.

Different ratios of fly ash used in four of the six sections on the Monona project. The other two were designated as control points and paved with conventional mix designs.

Ten percent of the portland cement was replaced on two sections with 1.5% fly ash being inserted in the mix for each 1% of cement taken out. A straight 15% ash replacement was used on a third section. The fourth also had 15% ash with a 1.5 to 1 percent replacement ratio.

Monona County Engineer Orville Ives stated he was confident that cost savings can be made without sacrificing strength, durability, or longevity of the pavement.

"In fact," Ives added, "I think we will end up with a better product that we had before."

"If it had all been fly ash, one mix rather than six, it would have gone for 0.20¢ a sq. yd. under all portland cement mixes," Ives said. "But add-ons were inevitable on this project because of equipment for the plant and other contingencies," he added.

Despite the add-ons, Ives termed the project cost about what "an all portland cement pavement would have cost."

Dick Pollard of Power Plant Aggregates of Iowa, whose firm supplied the ash for the Monona project, placed the potential cost savings at "\$1-\$2 a cu. yd. over a portland cement mix depending on the amount of fly ash used."

The 400 tons of fly ash used on the project came from Iowa Public Service's Port Neal Power Station in Sioux City located about 40-miles north of the job site.

Pollard stated the fly ash from Port Neal #3 Unit is a uniform ash that is very consistent and highly reactive.

The work was performed by crews from Irving F. Jensen Construction Co.



Feeding the CMI paver



The final touch

using conventional paving equipment. The contractor used Agitor and dump trucks to haul the mix to site and placed the cement with a CMI Autograder or paver.

The Jensen crew said the mix "fell out of the trucks in sheer planes looking dry and hard to work." But after the mix was slipformed it was "easy to finish and gave us no edgeline problems."

Huisman added fly ash is "not really a substitute for portland cement, but more of a catalyst, a supplement which aids portland cement in the cementing process."

The DOT official said his major concern is the question of logistics and the quality variation of the ash.

From a design standpoint, the DOT is interested in the handling properties of the fly ash mixes, their strength and durability, and their ability to maintain consistent air entraining or slump control.

(Project data and photos supplied by MID-WEST CONTRACTOR)



No edgeline problems

Seminars Well Attended

NAA Director John H. Faber participated in December fly ash seminars in Mitchell, SD and Ames, IA.

The programs dealt with the basics of fly ash utilization in ready-mix concrete, concrete products, and concrete paving. They were sponsored by Power Plant Aggregates of Iowa and Contech, Inc.

Fifty-four registered at Mitchell and 179 attended the event on the University of Iowa campus.

PPA Executive Richard A. Pollard reported the use of fly ash will be on the program at both the South Dakota and Iowa ready-mix conventions in 1979.

Ash Allies: Highway Materials Group

The Highway Materials Group (HMG) comprises 11 national associations representing companies that provide the construction materials and equipment essential to building America's roads, highways, and bridges. We employ tens of thousands of men and women in well-paying American jobs, and we strongly support increased investment in America's surface transportation network. The members of the HMG include the following organizations:

- American Coal Ash Association
- American Concrete Pavement Association
- American Traffic Safety Services Association
- Associated Equipment Distributors
- Association of Equipment Manufacturers
- Concrete Reinforcing Steel Institute
- National Asphalt Pavement Association
- National Ready Mixed Concrete Association
- National Stone, Sand & Gravel Association
- Portland Cement Association
- Precast/Prestressed Concrete Institute

HMG members work collaboratively to inform Congress and the Executive Branch of the federal government on the important issues affecting the transportation system that supports our economy. These associations hold meetings on a regular basis encouraging creation of adequate and sustainable funding. In addition, the HMG works to influence regulations that impact the delivery of transportation products.

The funding of highway construction and maintenance has historically come from fuel taxes collected for the Highway Trust Fund. But the federal gas tax has not been increased since 1993. If adjusted for inflation, the \$0.18-per-gallon federal excise tax on gasoline would be \$0.31 today. In addition, as vehicles have become more fuel efficient, less revenue is flowing to the Highway Trust Fund—even though Americans are driving more miles than ever before.

Moreover, in the last several years, the federal government has diverted funds from road and bridge projects to other

transportation modes, including mass transit and bike paths. Alternative power sources for cars and trucks also negatively impact road funding—and the advent of hybrid vehicles and electric vehicles has reduced revenue for our roads and bridges. Further development in compressed natural gas and hydrogen fuel cells will worsen the shortfall in funding.

The HMG has encouraged Congress to explore and test alternative funding mechanisms, such as user fees based on hours of operation or miles driven, to overcome the shortfall in funding from gas taxes alone. Many states have implemented alternative funding programs to meet their own transportation needs.

The American economy depends on a robust system of roads, bridges, highways, and runways. A growing and prospering society must be able to count on efficient mobility. The members of the Highway Materials Group are committed to helping improve and expand our surface transportation assets.



Welcome, New ACAA Members!

Following are companies and individuals that have joined the American Coal Ash Association since January 2017. ACAA membership now stands at 168.

Utility Members

Kansas City Board of Public Utilities is a not-for-profit public utility providing water and electric services in Kansas City, Kansas. It services 65,000 electric customers and 51,000 water customers over approximately a 130-square-mile area.

Ingrid Setzler - isetzler@bpu.com

Associate Members

ASH Mineral Solutions strives to help industrial clients obtain top dollar for their underutilized resources. Focusing on long-term opportunities with high upside, the company specializes in engaging potential consumers in new and emerging markets. The company also works to develop industry standards for engineered pozzolans, non-hydraulic cements, and other next-generation materials.

Andrew Hicks - ash.mineral@gmail.com

Bloomsdale Excavating Co. Inc.'s extensive experience includes a wide range of public, commercial, industrial, and residential projects, utilizing diverse construction capabilities in site development, infrastructure, mining, and environmental. Additional services include general contracting, construction management, and engineering.

Craig Drury - cmd@blex.com

BossTek provides industrial dust suppression, odor control, and air cooling technology solutions. The company rents industrial-strength misting cannons domestically and customizes equipment for sale in North America and internationally.

Marianne Payne - marianne@dustboss.com

Brad Cole Construction Co. Inc. is one of the largest and most qualified heavy civil construction companies in the southern United States. Working as a turnkey or a specialty contractor, the company performs site development, infrastructure improvement, and heavy civil construction services for complex construction projects and a wide range of customers.

Ron Cryer - ron@bradcoleconstruction.com

Brook Ridge Consulting LLC has over 25 years of infrastructure management, environmental expertise, and waste-to-energy market support, including pre-construction planning experience.

Robert Sevret - bsevret@brookridgeenv.com

CALM Initiative is a private, industry-funded consortium that works with industry experts to address the challenges presented by coal ash remediation, coal combustion energy production, and energy wastewater treatment.

Chris Hardin - chardin@energyenviro.org

Chesapeake Containment Systems is a professional environmental construction firm serving its customers with a wide array of geosynthetic products and installation services. Since 2007, the company has installed over 300 million square feet of geosynthetics and has over 100 years of combined experience in the industry.

Ryan Kamp - rkamp@ccsliners.com

Eklund Environmental is operated by Gwen Eklund, who serves on the American Coal Ash Association's Board of Directors. The firm has expertise in environmental policy and international standards, waste management, and climate-related issues associated with electric power generation.

Gwen Eklund - geklund@earthlink.net

Ellis Global has experience with small, medium, and industry-leading businesses delivering design, construction, and management services across a range of markets, including transportation, facilities, environmental, power, and energy.

Anne Ellis - anne@anneellis.com

Environmental Specialties International is the largest installer in the U.S of geosynthetic liner materials for environmental containment applications. The company is also one of the industry's largest providers of geomembranes, geocomposites, geotextiles, geocomposite clay liners, and related materials.

Carolyn Johnson - cjohnson@esiliners.com

Enviro-Sense LLC provides turnkey environmental projects under the direction of certified environmental professionals in every discipline associated with the industry (geologists, CHMMs, engineers, chemists, biologists, biochemists, agricultural experts, etc.). The individuals working with Enviro-Sense represent over 100 years of combined experience in the environmental field ranging from wetland delineation efforts to complex Superfund investigation and abatement activities.

Stephen Stringfield - steve@environmental-sense.com

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Glover Construction is a leading mass excavation firm whose projects include commercial, residential, airports and dams, highway and infrastructure, energy, and landfills.

Matt Glover - mglover@gloverconstruction.com

Hallaton provides lining systems for landfill construction and closures, golf courses, reservoirs, wastewater plants, power plants, agricultural needs, recreational facilities, national museums, and private residences. The company has experience with all geosynthetic products, including HDPE, LLDPE, PVC, PP, XR-3, XR-5, Hypalon, speciality liners, geocomposites, geosynthetic clay liners, geogrids, geonets, and geotextiles, as well as with specialty liners such as vapor barriers and floating covers.

Brad Reitz - Breitiz@hallaton.com

HDR is an architectural, engineering, and consulting firm that has worked on projects in all 50 U.S. states and in 60 countries, notable among them the Hoover Dam Bypass, Fort Belvoir Community Hospital, and Roslin Institute building.

Christine Harris - christine.harris@hdrinc.com

Industrial Development Advantage focuses on acquiring, redeveloping, and divesting environmentally distressed properties for itself and its clients. Their power plant and industrial site closure program is designed for companies, PRPs, and other stakeholders seeking a fixed-cost solution to retire, decommission, and clean up facilities for future beneficial re-use, whether the company desires to divest property or maintain ownership.

Brett Hickman - bah@indeadv.com

Leister Technologies is a manufacturer of hot air plastic welding equipment, process heat components, and laser welding systems.

Daphne Mischel - daphne.mischel@leister.com

NAES Corporation is an independent services company dedicated to optimizing the performance of energy facilities across the power generation, oil and gas, and petrochemical industries. The company uses its experience in operations, maintenance, construction, engineering, and technical support to build, operate, and maintain plants that run safely, reliably, and cost-effectively.

Dale Timmons - dale.timmons@naes.com

PQ Corporation is a leading global provider of specialty catalysts, services, materials, and chemicals that serve the following applications: fuels and emissions controls, consumer products, highway safety and construction, packaging and engineering plastics, industrial and process chemicals, and natural resources.

Urszula Miezio - urszula.miezio@pqcorp.com

Rain for Rent is a leading provider of temporary liquid handling solutions, including pumps, tanks, filtration, and spill containment. Projects range from flood relief to construction site

dewatering, sewer bypasses, and industrial plant turnarounds.

Nick Rapagnani - nrapagnani@rainforrent.com

Richard Kinch is an independent environmental consultant principally involved in addressing Environmental Protection Agency (EPA) requirements regarding coal ash management and beneficial use. He formerly served as Chief, Industrial Materials Reuse Branch, at EPA and is currently a member of the National Ash Management Advisory Board, which advises Duke Energy.

Richard Kinch - rjkinch@cox.net

RJ Smith Construction Inc. was founded in 1995, initially specializing in site development and heavy highway construction. Today, the company provides full-scale demolition while also focusing on environmental remediation, erosion control, recycling, utility infrastructure, and emergency services.

Richard Smith - richardsmith@rjsmithcos.com

RPM Solutions is a reclamation, ash management, and environmental services company using proprietary equipment technology and refined operating skills to provide an innovative approach to coal yard reclamation and ash pond management.

Michael Rafter - mrafter@rpmsolve.com

Sparstane LLC converts flue gas desulfurization (FGD) by-products into two high-value materials: ammonium sulfate fertilizer and recycled calcium carbonate. The company's technology provides a cost-effective, environmentally friendly recycling solution for this by-product of coal-fired power plants. The company's business proposition is to build, own, and operate facilities to address these FGD streams with little or no capital investment required by the utility.

Andrew Scholeck - ascholeck@sparstane.com

Tetra Tech is a leading provider of consulting and engineering services worldwide, with expertise in science, research, engineering, construction, and information technology. Tetra Tech's sustainable solutions help clients address their water, environment, infrastructure, resource management, energy, and international development challenges.

Don Grahlherr - don.grahlherr@tetratech.com

Marketer Members

ZAG International sources, markets, and sells a full complement of minerals and raw materials, as well as intermediate and finished products. A global leader in the development and supply of renewable and sustainable materials, the company executes all facets of the logistics supply chain to bring these materials and products quickly and efficiently from source to the user. ZAG also provides specialized strategic advisory and support services such as sourcing and freight, environmental assessment, market and feasibility studies, and project management.

Bill Stanley - william@zaginternational.com

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