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# Recycling and Reuse of Fly Ash Produced by Coal Burning Power Plants

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Fly ash is a recyclable by-product produced from burning coal to provide electricity. Less than half of the fly ash produced yearly is recycled; the rest is stored in lined ponds near the coal-fired plants. By understanding the chemical and physical properties of fly ash, we could use the fly ash in lieu of other mined materials such as agriculture lime or roadway embankments.

## What is fly ash?

Fly ash consists of the lighter particles that travel up from the coal furnaces during combustion. Bottom ash is the heavier particles that cling to the sides of the furnace and do not escape during the burning of coal. Fly ash particles range in size from 1 to 100 micrometers in diameter (EPRI, 2009) and are comprised of silica, alumina, calcium oxides and iron oxides (EPRI, 2009; Gutierrez et al., 1993; Izquierdo and Querol, 2012). Minor components of fly ash include magnesium, potassium, sodium, sulfur and

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titanium, and small quantities of other elements (trace) such as arsenic, chromium, lead, and mercury (EPRI, 2009, Gutierrez et al., 1993, Izquierdo and Querol, 2012). All naturally occurring elements can be chemically detected in coal fly ash (Jayaranjan et al, 2014). The specific elements and their amounts are dependent on the type of coal (lignite, sub-bituminous, bituminous, and anthracite) burned at the electrical generating plants. Similarly, coal components vary among different locations in the world where coal is mined (Izquierdo and Querol, 2012). Under certain environmental conditions, various trace elements may leach from the fly ash and into the soil, surface water, and ground water (Jayaranjan et al, 2014).

How much fly ash produced in US?

In the United States, 80 million to one billion tons of coal combustion products (CCP), fly ash and bottom ash are produced annually, with approximately 40% recycled ash (ACC, 2016; EPA, 2016) and the remainder landfilled. The amount of generated fly ash will continue to increase due to increasing needs for electricity. In 2010, Europe (ECOBA, 2014) produced 48 million tons of CCPs consisting of 66% fly ash, 21% gypsum and 13% bottom ash, boiler slag (a by-product that keeps bottom ash molten), and Fluidized Bed Ash (FBC – more efficient coal combustion technology). Approximately 40% of the European fly ash was reused in building and construction uses such as concrete blocks, blended cement or road construction (Blissett and Rowson, 2012).

How do regulatory bodies define fly ash?

In 2014, the EPA classified coal combustion residues as “non-hazardous” under the Resource Conservation and Recovery Act (RCRA), established regulatory requirements for landfilled fly ash, and supported fly ash recycling (EPA, 2014, 2015). EPA defines fly ash reuses in two categories:  encapsulated reuse and unecapsulated reuse (EPA, 2015).  Encapsulated reuses are concrete, concrete products or grout, and a published method exists to evaluate products in this category (EPA, 2015).  Uncapsulated reuses are unbound taking the form of slurry.

The European Union (EU) has directives that are ambiguous leaving most of the interpretation to the participating countries (ECOBA, 2014).  Without clear guidelines, most countries will choose the cost effective method of storage.  The UK has further interpreted the EU directives through a document called a “Quality Protocol” and it splits fly ash into three categories:  bound applications (concrete), grouting (aggregates in grouting fissures), and unbound or fill (ECOBA, 2014).

Can fly ash be used for construction?

Fly ash is a cost effective alternative to soil in roadway construction (Jayaranjan et al, 2014). Road construction soil needs to be inexpensive and allow for uniform compaction to withstand the constant weight of vehicles.  Fly ash is a low cost engineering fill material that can be used in large volumes in soil replacement for roadway embankments (Blissett and Rowson, 2012; EPRI, 2009; Kang et al, 2011).   Fly ash has found to be a suitable material to be used as a base and sub base foundation layers for pavement because of its self-cementitious property which is desirable in construction use in roadway applications (Blissett and Rowson, 2012, Edil et al, 2011).

Fly ash partly replaces ordinary Portland cement in concrete production (Jayaranjan et al, 2014, McCarthy and Dhir, 1999). Fly ash provides a low cost replacement of Portland cement which serves as the binding agent in concrete production and requires resources during mining and refining processes. Fly ash enhances drying with reduced crack-width and free drying shrinkage (Jayaranjan et al, 2014, yang) and also has technical benefits in the production of concrete (Blissett and Rowson, 2012, Hassett et al, 2005). Fly ash is used in concrete production due to the fly ash's ability to react with calcium hydroxide (pollolanic property) and self-hardens (EPRI, 2009, Kang et al, 2011).

Fly ash is used as the under layer for putting greens and bunkers found at golf courses (Schlossberg, 2007). The grass clippings from bermudagrass, centipedegrass, and bentgrass from fly ash amended soils did not exceed regulatory levels (Schlossberg, 2004, 2007). Fly ash has been applied at high levels to centipede grass and bermudagrass to evaluate the plants response and both studies determined that plant growth was not affected and there was an increase in plant available water (Adriano, 2001; Schlossberg, 2004).

Can fly ash be used as soil amendments?

Fly ash has many beneficial uses in soil amendments. Using fly ash in sandy soil improves the water retention capability (EPA, 2015; Ukwattage et al, 2013; Pathan et al, 2003) which is believed to be due to the spherical nature of the fly ash particle (EPA, 2015; Yanusa et al, 2011) Fly ash's low bulk density (McCallister, 2002) allows for greater size soil pores for water storage. The calcium carbonate found in fly ash will increase soil pH (Yanusa et al, 2011, McCallister, 2002) similarly to using agricultural lime to increase of soil pH.

What are environmental concerns for using fly ash?

There are many heavy metals associated with fly ash (EPRI, 2009). Heavy metals, such as arsenic, chromium, lead, mercury, are present in the coal before incineration and the trace metals later reattach to the surface of fly ash particles (Izquierdo and Querol, 2012; Kukier et al, 2003). Trace elements found within fly ash present concern with surface water and ground water pollution (Ishak et al, 2002; Carlson and Adriano, 1991) and the plants that grow in the fly ash are subject to the gradual uptake of these metals. The type, size, and chemical composition will vary the type of reuse application of the fly ash (Blisset and Rowson, 2012; Gutierrez et al, 1993).

Routine use of fly ash in agriculture could lead to elemental toxicity to plants (Carlson and Adriano, 1991; Taylor and Schuman, 1988) by the repeated soil application of fly ash that over time, allows the heavy metals to accumulate and be available to plants and animals for uptake. Increased applications have shown to induce nuclear alterations in maize plants (McMurphy and Rayburn, 1993; Yanusa et al, 2008) and constant exposure to high concentrations of fly ash resulted in DNA alterations. Reusing fly ash in roadway applications could lead to contaminants leaching to groundwater and runoff to surface water (Kang et al, 2011; Luther, 2010).

There are various studies about the earthworms' response to fly ash amended soils when used together describe some of the soil ecology (Yunusa et al, 2007, 2009). In subsequent studies, a team of researchers studied two different species of earthworms and their short-term response to fly ash amended soil and the earthworms burrowing habits (Yunusa et al, 2007, 2009). The studies found that the earthworms were not adversely affected when fly ash was applied to agricultural soils at 5 Mg $ha^{-1}$ (Yanusa, 2007), but the size and depth of the burrows were altered (Yanusa, 2009). Another group studied the earthworm population in heavy metal contaminated soil that was amended with fly ash (Grumiaux, 2015 and found that certain species of earthworms, *Eisenia fetida,* avoided the fly ash but another species, *Lumbricus castaneus*, are more tolerant of the fly ash amended soil (Mnkeni, 2016).

What types of toxicity tests are currently performed on fly ash?

There are various leaching studies and the most often request study is the toxicity characteristic procedure designed by the EPA (Hassett et al, 2005; EPA, 2014). There are three types of leaching methods: regulatory, standard methods from various organizations, and research (Hassett et al, 2005), which are used by certain organizations that use a specific set of materials in a specific environment. Research methods generate different test procedures to generate the same correlative results as other test methods. There are parties that believe that the TCP by the EPA is too harsh of a test procedure and does not represent what happens in the field (Stewart, 2001; Kosson et al, 2002; Ram et al, 2007). In extraction testing, an extractant is used to pull out contaminants in a solution called the leachate that is tested for various heavy metals (Bushell and Williamson, 1996; Zandi and Russell, 2007).

Current research focuses on the leaching test procedures and the reliability of testing. One researcher discusses the various testing methodology and how they try to correlate data but leave out important factors such as extractant volumes, sample size and test durations (Proceedings of Technical Interactive Forum, 2002). Another researcher has commented that the laboratory testing might not reflect what is actually happening in the field (Hassett et al, 2005). For example, in the laboratory there is a quick extraction process and the secondary reactions do not have enough time to take place. They also commented that there was a decrease of the element concentration over time.

## Conclusion

Fly ash is a recyclable material that should be used in a variety of applications; cement, road construction, and agricultural lime are just a few uses reviewed. The rate of fly ash accumulation will increase with the production of energy. Careful analysis of the fly ash before reuse would minimize environmental impact; yet provide substitute raw materials in construction and agriculture.

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