



# HARVESTED FLY ASH AS A SUPPLEMENTARY CEMENTITIOUS MATERIAL—TechNote

Keywords: beneficiation; coal combustion products; disposed; fly ash; harvested; reclaimed; recovered.

## Question

Does fly ash stockpiled in ponds or landfills retain its ability to provide functional benefits to concrete?

## Answer

Fly ash harvested from either landfills or ponds is being used in concrete today, providing the same functional benefits expected from fly ash collected directly from a coal-fired power plant. However, harvested fly ash typically requires some processing to meet applicable specification limits.

## Discussion

*Background on fly ash availability*—Using fly ash as a supplementary cementitious material (SCM) in hydraulic-cement concrete is a well-known and widely used practice. Fly ash provides many benefits to both fresh and hardened concrete (ACI 232.2R). Fly ash historically has been sourced directly from electric coal-fired power plants as it is produced. However, many North American coal-fired power plants have closed or converted to natural gas, causing a reduction in ash production. Figure 1 shows an approximate 40% reduction in coal-fired generation of electricity during the period from 2010 to 2017 (USEIA 2020). The corresponding production of fly ash has declined substantially, as shown in Fig. 2. Another compounding factor that has impacted fly ash availability for use in concrete is the enactment of mercury, sulfur, and other emission standards for power plants by the Environmental Protection Agency (EPA) (EPA 2011). These standards have driven coal-fired power plants to install emission control technologies—for example, dry sorbent and activated carbon injection that is sometimes installed before the point where fly ash is collected. Therefore, sorbents such as sodium bicarbonate ( $\text{NaHCO}_3$ ) and activated carbon, and any products resulting from their reaction with the flue gases, are combined and collected with the fly ash, which in many cases can compromise the quality of the fly ash. Technologies are available to address activated carbon in fly ash. However, high levels of sulfur compounds from sodium and calcium sorbent injections can make fly ash impacted by these emission control technologies noncompliant with current fly ash specifications for use in concrete.

Despite the decrease in fly ash availability, the amount of fly ash used in concrete increased by approximately 29% from 2009 to 2019 as a result of efforts made to improve storage and distribution networks, as well improvements in fly ash collection systems and shifts of fly ash use from other applications to concrete. These factors combined make the concept of harvesting fly ash an important supply option for regions where fly ash is in short supply. To meet the concrete industry's demand, utilities and the fly ash industry have started harvesting legacy fly ash deposits (NCPTC 2021).

The American Coal Ash Association (ACAA) surveys utilities each year to determine the quantity of fly ash produced and the fraction beneficially used. Figure 2 shows the difference between the amount produced and the amount beneficially used.

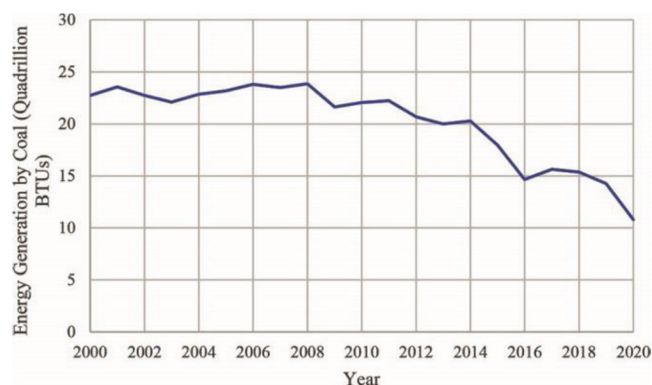


Fig. 1—United States electricity generation from coal, 2000–2020 (USEIA 2020).



This represents the fly ash reserves in disposal or storage. Since 1966, the year ACAA started conducting the survey, over 1 billion tons (0.9 billion tonnes) of fly ash have been sent to landfills or ponds. The total ash disposed in landfills and impoundments since the inception of pulverized coal generation in the early 1900s is estimated to be nearly 2 billion tons (1.8 billion tonnes) (ACAA 2020). Unused fly ash was either sluiced to ponds or lagoons known as surface impoundments or transported to solid fill sites, embanked, and covered. In some cases, other materials such as bottom ash, mill rejects containing pyrites, and flue gas desulfurization (FGD) materials may have been comingled with fly ash during placement, making some sites more challenging for beneficiation.

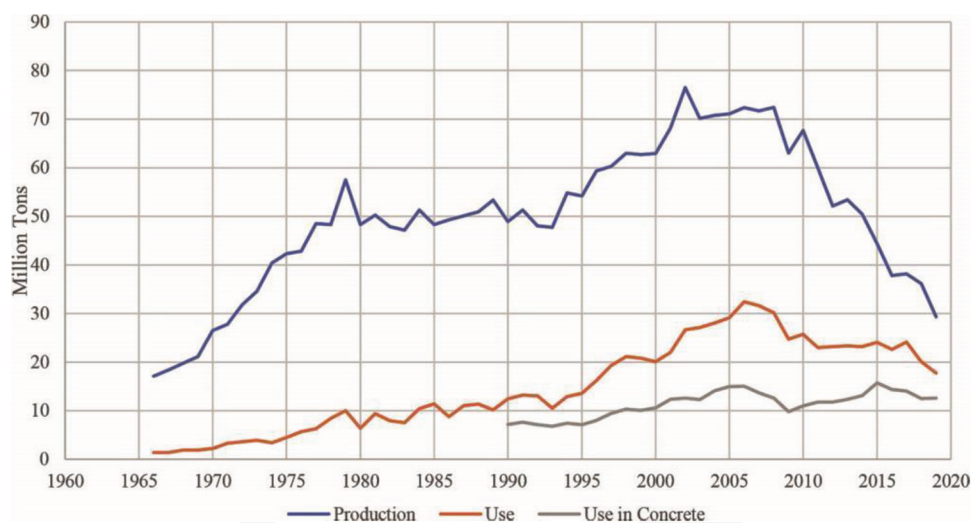


Fig. 2—Production and use of fly ash in the United States (ACAA 2020).

*Properties of harvested fly ash*—Harvested fly ash varies in properties from source to source, similar to freshly produced fly ash. However, harvested fly ash is typically pozzolanic (Diaz-Loya et al. 2019; Al-Shmaisani et al. 2018). A survey conducted by the EPA showed the pH in fly ash storage sites did not exceed 8.2 (EPA 2015). A highly alkaline environment is required to initiate and sustain a pozzolanic reaction and that environment does not exist in these sites. Therefore, ponded or landfilled fly ash remains pozzolanic after years of storage. It is important to note that harvested fly ash may have partially reacted hydraulically in storage, depending on the CaO content (Wirth et al. 2019; Milla et al. 2019).

The pozzolanic characteristics of a representative harvested ash used in concrete are illustrated in Fig. 3, which shows the calcium hydroxide ( $\text{Ca}(\text{OH})_2$ ) content of hardened cement paste samples. The  $\text{Ca}(\text{OH})_2$  content was measured for a portland-cement-only control sample and three test samples, all prepared with a 0.40 water-cementitious materials ratio ( $w/cm$ ) using thermogravimetric analysis (TGA). The samples were cured for 35 days at  $104^\circ\text{F}$  ( $40^\circ\text{C}$ ). Figure 3 compares the portland-cement-only control sample with the test samples where 20% of the cement was replaced with: a) Class F silo-stored fly ash; b) Class F harvested fly ash from the same plant; and c) ground quartz, an inert material. The results show the  $\text{Ca}(\text{OH})_2$  content of the paste in the harvested and silo-stored fly ash samples is less than that of both the control and the paste mixtures containing inert material. This result is due to  $\text{Ca}(\text{OH})_2$  consumption by the pozzolanic reaction and indicates both fly ash materials are pozzolanic (Diaz-Loya et al. 2019).

*Effect of harvested fly ash on fresh properties of concrete*—Studies focused on harvested fly ash, processed by drying and milling to a particle size meeting the requirements of ASTM C618, have focused on concrete performance showing some differences but overall comparable performance to silo-stored fly ash. One such study reported improvement of concrete workability as measured by slump when proportioning concrete with harvested fly ash (Al-Shmaisani et al. 2019), while another reported the opposite when using harvested fly ash, indicating the need for a water-reducing admixture to improve workability (Milla et al. 2019). Similarly, Al-Shmaisani et al. (2018) reported that harvested fly ash has a similar effect on concrete set time as silo-stored fly ash (that is, a slight delay compared to concrete proportioned with cement alone), while a study conducted by Milla et al. (2019) reported a slight decrease in set time compared to concrete proportioned with cement alone.

Milla et al. (2019) also reported the effect of harvested fly ash on concrete unit weight and entrained air content was similar to that of silo-stored fly ash.

*Effect of harvested fly ash in hardened properties of concrete*—Concrete proportioned with harvested fly ash has shown to have similar strength development and other hardened properties compared to concrete proportioned with silo-stored fly ash. Studies have reported harvested fly ash exhibited similar strength development, modulus of elasticity, and volume stability as silo-stored fly ash in concretes with  $w/cm$  of 0.35, 0.4, and 0.47 (Al-Shmaisani et al. 2018; Milla et al. 2019).

*Effect of harvested fly ash in concrete durability*—Several studies have shown harvested fly ash is effective in mitigating alkali-silica reaction (ASR) (Diaz-Loya et al. 2019; Al-Shmaisani et al. 2018; Kaladharan et al. 2019). Figure 4 shows the