Ash pond erosion process monitoring using LiDAR scans

Shen-En Chen i), John Daniels ii), Zhengfu Bian iii) and Shaogang Lei iv)

i) Professor, Department of Civil and Environmental Engineering, University of North Carolina at Charlotte, 9201 University City Boulevard, Charlotte, NC 28223-0001, USA.

ii) Professor and Chair, Department of Civil and Environmental Engineering, University of North Carolina at Charlotte, 9201 University City Boulevard, Charlotte, NC 28223-0001, USA.

iii) Professor and Vice Chancellor, Institute of Land Resources, China University of Mining Technology, 1, Daxue Road, Xuzhou, Jiangsu, China.

iv) Associate Professor, Institute of Land Resources, China University of Mining Technology, 1, Daxue Road, Xuzhou, Jiangsu, China.

ABSTRACT

The management of coal fly ash continues to transition from wet methods (e.g., sluice to settling ponds) to dry methods (compaction of ash into landfills). The closure of ash ponds and creation of ash landfills typically require designs which minimize infiltration and erosion. Impoundment practices such as dams for mine tailings and coal fly ash ponds accumulate constituents which, under certain conditions, may be hazardous to human health and the environment. Since most impoundments are exposed without protection, rain can induce erosion and generate leachate. Further, rain impact on ash erosion can cause massive ponding failures and resulting in spills. To monitor ash pond erosion process due to rain and possible use of chemical stabilization method to protect slope surfaces, terrestrial LiDAR is used to study simulated rain falls on ash slope. This paper reports laboratory studies using small-scale rain simulator and LiDAR scans to quantify mass loss due to rain impact.

Keywords: ash ponding, rain erosion, organosilanes treatment, terrestrial LiDAR scan

1 INTRODUCTION

Coal fired production processes generate significant amount of byproducts, including mine tailing materials and post-production ash. Current state-of-practice for tailing materials from coal mining and ash from coal combustion is to store them in tailing impoundments or ash ponds (EPA 2014). Due to the nature of the chemical contents in the tailing or ash materials, which may include heavy metals and other hazardous constituents, impoundment designs should be able to prevent leachate and subsequent contamination of ground water and soil. Ash may be handled relatively dry and mechanically compacted in landfills. In these instances, the surface of the ash may be exposed to the forces of wind and rain, with concomitant potential for erosion and leachate generation. Wet methods such as sluice to settling ponds usually require large amount of water, thus is less welcomed as a storage method.

2008 ash spill at the Tennessee Valley Authority (TVA) Kingston site raised serious concerns about the effect on human health due to the storage of ash in impoundments (ORAU 2010). Moreover, U.S. Environmental Protection Agency (EPA) considered many existing impoundments as posing a hazard in the event they would fail. (C&EN, Feb 23 2009). There is a need for developing techniques that can ensure safe storage of ash until competent ash reuse technologies are being developed.

To protect ash pond hazardous materials from entering into the environment, Daniels et al. (2009a, 2009b and 2009c) proposed using organosilanes (OS) as an ash treatment material. It is noted that the formation of hydrophobicity on slope surfaces may protect airborne ash dust as fugitive emissions. Organosilanes can be altered to become either hydrophobic or hydrophilic and has been found to pose minimal environmental impacts (Graiver et al. 2003).

Ellison (1944) described three mechanisms of rain-induced soil erosion: 1) loss of soil through surface runoffs; 2) loss of soil through raindrop splash; 3) erosional activities due to soil flow. Typical rain erosion of slopes resulted in rill and gullies, which eventually resulted in large runoffs that carried the ash particles into natural streams, resulting in surface water pollution (Figure 1). Untreated ash surface relies on compaction to resist run-offs (Pitt et al. 2008).

This study investigates rain fall impacts on the design of spray-on OS as an agent to make the tailing surficial materials water-repellent such that the rain water will flow off the surface, such technology falls
under the category of chemical treatment system. To simulate rainfall, two specially designed raindrop mechanisms are used in the laboratory testing. The first laboratory test setup provides a centimeter-range erosion simulation. The second laboratory test is a scaled up version of the first laboratory test. 3D LiDAR scans were used to quantify erosions due to simulated rainfalls. Terrestrial LiDAR scanner generates 3D point clouds with coordinate information and will be used to provide volumetric quantification of the eroded slopes (Liu et al. 2010, 2012, 2013, Watson et al. 2012, 2013).

Fig. 1. Schematic of rain erosion on ash ponds without treatment.

2 SMALL-SCALE EXPERIMENTAL SETUP

Figure 2 shows the experimental setup which consists of a spigot head, tilting ash tray and a particle collection tray (Amburgey 2007). The spigot head is designed to allow dripping of water uniformly along a line. The elevated water tank and the perforated pipe simulate rain drop process (33 cm above the ash tray base), which resembles a falling head conductivity test. The coal ash is compacted into the tilt-able Plexiglas tray (30 cm length × 23.5 cm width × 4 cm depth).

Fig. 2. Schematic of small-scale erosion test apparatus.

Figure 3 shows the side view of the experimental setups. The slope of the ash tray can be altered for different slope angles up to 30 degrees. For this study, a 15 degree angle is maintained resulting in a 29 cm drop height for the rainfall simulator. The ash sample is Class F coal ash donated from a utility in the southeastern U.S. The OS used in this study is Zycosil (from Zyderx) which forms siloxane (=Si-O-Si=) bonds with the ash particles and made them hydrophobic via the quaternary structure with a long alkyl chain (C_{18}H_{37}). In this study a 10% OS solution mix is used.

Fig. 3. Side views of small-scale erosion test apparatus.

The samples are first prepared by mixing the necessary water to ensure consistent water content in all samples of 5% by weight. Two types of samples are used: without OS treatment (VFS1 to 4) and with OS treatment (10F1A-4A). To create OS-treated surfaces, OS solutions (diluted 1:10 with DI water) were sprayed onto the surface of the compacted ash. As such, the treatment resides at the surface and extends 2-5 mm into the matrix. Below this depth the ash remains untreated. 30 mL of water was filled into the reservoir and allowed to free wall upon the ash slope.

The laser scanner is then setup to conduct a scan and the mass loss is then calculated (Figure 4). Mass loss is calculated using the scanned surface area of loss times an averaged depth (determined from laser scan):

\[
\text{Mass loss} = \text{computed surface area} \times \text{average depth} \quad (1)
\]

Fig. 4. Laser scanner positioned to scan samples.

3 SMALL-SCALE EXPERIMENT RESULTS

The laser scanner used in this study is a Faro X-series scanner from Faro Technologies Co. A total of eight tests have been performed including four for untreated samples (labeled as VFS) and four for treated samples (labeled as 10FA). Figure 5 shows a typical untreated ash surface after rainfall test: Visible are a horizontal washed-out zone resulted from rain drop impacts and
wash-offs. Depending on localized variations in the level of ash compaction, impinging water formed rills as it was conveyed downslope. In this case, some of the water drained off the sides of the ash tray forming gullies on both sides of the tray. The washed-out zone appeared to be highly disturbed due to the impact forces and splashing of the water drops.

Figure 5. Typical eroded surface of untreated sample with horizontal washed-out zone showing highly disturbed surface.

Figure 6 shows a typical scan reflectivity result on OS treated samples. A horizontal zone of impact was formed directly underneath the perforated pipe, i.e., the source of simulated precipitation. From that point, there were multiple rills which formed orthogonal to the main zone of impact as water is conveyed downslope. Careful study of the treated samples indicated that the rills were formed by running under the treated ash surface. This observation is significant since it indicates that while hydrophobicity and a reduction in erosion is possible with treated surfaces, these surfaces may be breached as a result of the impact of rain drops. Once water has breached the treated surface, subsequent erosion of the untreated material proceeds from underneath the treated surface. The erosion caused the surface to form arches as shown in Figure 7.

Figure 6. Scanned surface of OS treated specimen: eroded surface revealed formations of arches with most water ran off the surface as sheet flows.

In cases where the rain drop impact was not sufficient to break through, the water would run off the sample surface without disturbing the sample, a clear indication that the sample has become hydrophobic.

Laser scans were performed on the treated samples after the rainfall test. Figure 8 shows the laser scanned images of the four tests performed on treated ashes where moderately disturbed surfaces were observed. Automated mass loss calculations were then performed on the scans (Liu, 2010). Figure 8 displays the computed areas from the OS treated samples, which are fragmented as a result of arching. Figure 9 displays the computed areas from the non-treated surfaces, which showed mostly connected surfaces. The missing sections for sample 10F2A and 10FA4A were due to inadequate resolution of laser. Table 1 summarized all the small scale laboratory test results including the mass loss calculations and depth of penetration calculations. Also observed in Table 1 are the presence of arching in the tested samples.

The averaged mass loss of the untreated samples (0.000297m³) was slightly higher than the mass loss of the treated samples (0.000191m³). The average depth of penetration for untreated samples (0.01375m) was slightly shallower than treated samples (0.01425m).

Fig. 7. Formation of arching indicated water runoff under the OS treated surface; the observation of water beads and relatively undisturbed surface indicates effective deterrent of treated surface against runoff.

Fig. 8. Laser scanned surface of OS treated specimen (VFA): Horizontal washed-out zones show moderately disturbed surfaces.
Fig. 9. Laser scanned surface of non-treated specimens (10F): Horizontal washed-out zones are mostly continuous.

Table 1. Summary of laser scan mass loss calculation.

| Sample | Arching | Mass Loss (m³) | Depth (m) |
|--------|---------|---------------|-----------|
| VFS1   | No      | 0.000175      | 0.012     |
| VFS2   | No      | 0.000231      | 0.016     |
| VFS3   | No      | 0.000203      | 0.013     |
| VFS4   | No      | 0.000581      | 0.014     |
| Average|         | 0.000297      | 0.0137    |
| 10F1A  | Yes     | 0.000170      | 0.014     |
| 10F2A  | Yes     | 0.000186      | 0.014     |
| 10F3A  | Yes     | 0.000219      | 0.016     |
| 10F4A  | Yes     | 0.000189      | 0.013     |
| Average|         | 0.000191      | 0.0143    |

4 SCALED-UP TEST

A large-scale test setup is constructed at the China University of Mining Technologies (CUMT). Figure 21 shows the test setup which consists of a built-up cage and a perforated pipeline simulating rain drop. The base of the ash cage is about 2m by 2m and is constructed from 2m x 1.4m and 2m x 0.6 m plywood sheets and 3 m long wood beams. Rainfall test was conducted and laser scan was performed only on the OS treated sample. The purpose of the test is to determine the effectiveness of OS treatment as a result of harder rain fall impacts (1 m drop).

5 SCALED-UP TEST RESULT

The rainfall test was first performed on the untreated sample. Figure 10 shows the test result: Similar to the small scale test, the line spray from the rainfall simulator resulted in horizontal washed out zones and long rills. The left-hand side ended with a 0.7m long washed out zone with a significant 1m long rill. The right-hand side ended up with a 0.6m long washed out zone and a 2.06m long rill. Due to the extended travel length, the rills were shown to branch out near the bottom of the test setup. The washed out zones were shown as deep gullies. Attempt to measure the depth of the gullies indicated at least 5cm deep.

Fig. 10. Erosion on untreated sample after 10 minutes rainfall simulation showing two eroded sections with washed out zones and rills.

Figure 11 shows the test result of the OS treated surface test. A 10% OS diluted solution was sprayed on the ash surface as treatment. Using 10 minutes of rain fall, deep gullies of washed out zone were formed. However, the washed out zones were observed to be significantly narrower than the previous test and with notably limited rill formation. Again two washed out zones can be observed. The left side washed out zone appeared to be a single cavity with likely two rills forming. The right side washed out zone had significant arching that divided it into two parts.

Fig. 11. Erosion on OS treated sample after 10 minutes rainfall simulation showing two eroded sections with washed out zones and rills.
The outcome of mass loss calculation is shown in Figure 12, where the relatively light areas is the rainfall influenced zone indicating two rills. Computed mass loss is about 0.13 m\(^3\) with surface area of 3.409 m\(^2\).

![Laser scan image for mass loss calculation.](Fig. 12)

6 DISCUSSION

Both small scale and scaled-up laboratory experiments appear to reproduce the intended physical phenomena as shown in Figure 1. The small scale experimental setup did not have long enough flow path for the ash samples to demonstrate rill and gully erosions, which were nicely reproduced in the scale-up test setup.

OS treatment on the ash slope has two essential effects: 1) making the surface ash hydrophobic and 2) creating weak bonding between the ash particles. The effect of rain fall impact on the treated ash surface is critical because the rain drop force can break through the treated surface and resulted in erosion. This indicates that the bonding between ash particles due to the OS treatment is not sufficiently strong against rain impact. Otherwise, the OS treatment has demonstrated the ability to make the ash surface hydrophobic.

The 3D laser scan is shown to be an effective method to monitor ash mass loss on ash ponding slopes. Further development of both test setups may be able to reduce experimental errors and reduce the similitude differences. Future work also includes making OS treatment with improved physical resistance to rain impact to enhance its effectiveness.

7 CONCLUSIONS

Laboratory erosion tests were conducted to evaluate the efficacy of OS treatment on compacted ash, analogous to an ash pond application. The laboratory tests have successfully captured the rain erosion process that would have caused mass loss and leachate during heavy rain. A scale-up test confirmed similar observations. 3D laser scan has successfully quantify the mass loss of the rain-impact samples. Future study will include making OS treatment with improved physical resistance to rain impact to enhance its effectiveness.

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