Beneficial Re-use of CCR for Site Closures using Mining Reclamation Technologies

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ABSTRACT

Coal combustion residuals (CCR) have been used to backfill underground and surface coal mines since the 1970s, offering not only a cradle-to-grave materials management approach, but also mitigating some of the adverse environmental effects of coal mining. Therefore, issuance of the CCR Rule makes the design premises behind the use of CCR in mine reclamation, as well as the construction methodologies employed, more relevant than before. Properly managed CCR materials, used in well-engineered applications, offer a degree of permanence for ash pond closures and abandoned mine reclamation projects. Where such materials are readily available, they can be used as engineered materials that can be used effectively to control the flow of water, stabilize slopes, improve access roads, and mitigate environmental impacts from acid mine drainage and methane, among others.

Due to the applicability of CCR as a building material, clients and contractors alike should entertain the recovery of CCR materials from ash impoundments for use in on-site construction of stormwater channels, dam improvements, caps, revetment walls, and other closure infrastructure. Decades of use of CCR construction materials in mine closures have provided important leachability data and offer some lessons learned that can now be applied to a wide range of closure tasks. Similarly, abandoned mine sites across the country may be able to accept encapsulated CCR as backfill for mutual benefit of clients and state-run abandoned mine programs alike. This paper explores the various considerations behind use of these materials and specifically brainstorms value-added construction methodologies that draw from the prior long term use of CCR backfill materials in mines.
OVERVIEW OF ISSUE

The CCR Rule, published by the EPA in April 2015, has specific guidelines that dictate the appropriate beneficial re-use of encapsulated and un-encapsulated CCR materials. Encapsulated CCR materials are those which “bind the CCR as part of a solid matrix that minimizes their mobilization into the surrounding environment.” At present, the ruling places a limit of tonnage of un-encapsulated materials that may be utilized, whereas there is no limit on the use of encapsulated materials which would include manufactured concrete, wallboard, and rubber or plastic filler.

CCR have been used as mine backfill since the 1970s, and most often have been incorporated into a grout for placement in underground mine voids or over surface mine cuts. Their use has often been limited by the rate of acceptance of fill materials dictated by the mines themselves, as no limit has ever been placed on their use for mine backfilling. In 2003, only 2.27 million tons of CCR were used as mining backfill whereas 122 million tons of CCR were produced by the industry. About 38% of all CCR was beneficially reused in 2003, with less than 2% used as mining backfill.

Where CCR were used as mine backfill, they have decidedly improved the quality of groundwater resulting from uninterrupted flow of air and water through and over underground and surface workings. Coal mining, like hard rock mining, exposes sulfidic rocks to water and oxygen which supports microbial actions capable of accelerating acid generation (sulfuric acid) and leaching heavy metals that can be perpetuated over geologic time. Where such interactions can be minimized, such as through mine void backfilling, the rate and volume of interaction by-products can be greatly reduced and groundwater and surface water quality improved.

Previous backfilling projects have shown that groundwater flow through underground workings can be greatly impeded using CCR as backfill. It has also been demonstrated that many heavy metals, which are high in concentration in mine runoff, such as iron, cadmium, lead, arsenic, and others, are reduced when water flows through encapsulated CCR rather than through the exposed mine workings. While there are a few sites where certain constituents have higher concentrations after flow through encapsulated CCR, including boron, arsenic, nitrate and nitrite, sulfate, and chloride, the net environmental benefits provided have been recognized as substantial due to the otherwise limited options to manage the range of complexities present through natural interactions. As well, the flow rate at these sites is reduced so greatly that the mass loading of these constituents could be considered more relevant data regarding the change in water quality.

Beyond water quality changes and overall improvements, mine and spoil pile fires, subsidence mitigation, and hydrological improvements can also be accomplished through beneficial re-use of CCR backfilling programs. Underground mine voids that might be unstable and collapse, or others that might pose mine fire risks can be filled. Grading improvements at the ground surface can be constructed using CCR concrete.
materials to slow water flow or direct run off toward particular portions of the site, and to dedicated discharge points. These same concepts can be utilized at mine sites going forward, or can be utilized by utilities during site improvements and pond closures.

Where native materials are specified for use in buttressing, road construction, stormwater and erosion control, or other closure tasks, alternate use of encapsulated CCR materials may be less expensive due to their availability. This serves the dual purpose of reducing construction costs and beneficially reusing CCR rather than impounding them or disposing of them as necessary. This paper focuses on the potential for these uses from a technical standpoint, to offer some considerations for utility owners and regulators alike. The applicability of these uses will come down to economic realities, which will vary by site.

REGULATORY FRAMEWORK

The CCR Rule (40 CFR 257 and 40 CFR 261) does not apply to CCR that are beneficially reused. Beneficial reuse relevant to construction materials and backfill materials, is defined by the CCR Rule as use which provides a functional benefit, replaces use of alternative materials, and meets product specifications and relevant regulations. Encapsulated CCR materials used as mining backfill or used as alternative materials for site improvements would qualify as beneficial reuse, and therefore is exempt from compliance with the CCR rule.

While the new rule does not apply, the Surface Mining Control and Reclamation Act (SMCRA) and State Rules governing reclamation of mine land, as well as regulations governing water quality standards must be met. The primary concern with use of CCR materials is their potential to leach heavy metals and other harmful constituents into surface or groundwater. The leachability tests that apply to materials made with CCR have undergone method development to replace the standardized toxicity characteristic leaching procedure (TCLP) and synthetic precipitation leaching procedure (SPLP) tests. Prior to use of CCR encapsulated in construction on site, or as backfill, the leachate tests and monitoring requirements required by the state regulators must be understood. Future federal regulations, if applied, will likely be concerned with long term groundwater impacts, and therefore bench scale leachability tests are important to discern the specific risks at each site, which will be discussed in more detail in the section regarding the benefits of CCR re-use.

MINE RECLAMATION CONSIDERATIONS

Abandoned coal and hard rock mines exist in large numbers across the United States, many of which are associated with hazards including acid mine drainage, subsidence,
and slope failures. The most salient and difficult of these challenges is the mitigation of acid mine drainage, as the production of acid mine drainage occurs over long periods of time; furthermore, as the flow of water through abandoned mines is largely uncontrolled, bulkheads must be engineered and installed to preferentially direct drainage to designated outfalls for management. As noted, coal mining, like hard rock mining, exposes sulfidic rocks to the elements and to new microbes, which creates sulfuric acid, which leads to acid mine drainage and leaches heavy metals over geologic time. Where the interaction between these exposed rocks and the elements can be limited, and where the water pH can be raised through contact with lime or other basic materials, groundwater and run off water quality can be improved prior to drainage as demonstrated in Figure 1. Otherwise, this drainage often requires active or passive treatment system construction, operation and maintenance.

![Abandoned Mine Void Schematic](image-url)

**FIGURE 1 – Abandoned Mine Void Schematic**

At the same time, mine voids can collapse within the subsurface, continually re-exposing mine materials to groundwater exposure while also leading to potential surface subsidence. This bulking effect leads to a direct loss of strength in the underlying rock left by the mine voids. This problem can be effectively mitigated through
elimination of the resulting voids by backfilling, with the added benefit of limiting groundwater flow through such materials and the net effect of acid mine drainage.

COAL ASH AS BENEFICIAL BACKFILL

Coal ash pond closure projects and mining reclamation projects have a few infrastructural improvement requirements in common. Ash pond dikes may require structural additions or repairs and slope stabilization. Stormwater diversion will be required and in some cases, may have to be demolished and replaced to accommodate for greater flow velocities. The materials required for these improvements may be a major project expenditure that can be off-set through the creative use of encapsulated CCR materials, as has been accomplished by mine owners in the past.

Mining reclamation requires a host of materials to achieve a closure objective. Often these materials include structural fill, low permeability cap materials, topsoil, rip rap, concrete, and other aggregate that must be mined, transported, and placed at the site. Reclamation projects can be in remote areas that are not as easily accessed by truck traffic, making some transportation options difficult and costly. CCR may be more economical to transport using existing rail lines and partnerships between mine operators and coal utilities, and replace a need for mining of virgin materials.

CCR additionally have excellent structural properties that have been recognized by many industries. CCR may be a favorable substitute for native construction materials depending on the objective of the project: fly ash is a low permeability material, which has pozzolanic properties when used as an additive, bottom ash is an excellent replacement for structural fill and base course, and when these materials are mixed with cement to form concrete, the concrete has comparable strength properties and may be less expensive to produce.
Beneficial structural properties can be specifically validated in the laboratory using bench scale testing that mimics full scale construction methodology, followed by geotechnical testing to provide data that can be communicated to regulators and can be generated as construction specifications.

Where CCR have been used as mine backfill, they have not adversely impacted ground or surface water resources as far as monitoring data is available. Decidedly, they have improved the quality of the groundwater affected by acid mine drainage, generated from uninterrupted flow of air and water through and over underground and surface workings. CCR grouts in particular have been desirable as backfill as the fly ash additive has low permeability ($1 \times 10^{-7}$ centimeters/second as an average) and the addition of Portland cement, lime and/or flue-gas desulfurization (FGD) material raises the pH of the material. One popular water treatment process to address acid mine drainage is a limestone drain, which produces either a high oxygen or low oxygen environment and high pH to promote precipitation of heavy metals. Use of CCR grout materials at the point of acid mine drainage generation (in the mine) supports an elevated pH environment that counteracts the generation of sulfuric acid and therefore can reduce the heavy metal loading from these AML sites to the surrounding environment. Augmentation of these grouts with bentonite provides the capacity to enhance the effectiveness of the approach by even further by reducing permeability even more and increasing the likelihood of naturally-mediated sequestration.

These hydrologic and water quality benefits can also be validated on a bench and pilot-scale level, with leachate and permeability tests conducted on various materials including CCR grouts to determine the optimal percentages of additives and to anticipate long term groundwater impacts.

It has been shown through grout coring in backfilled mines that hydraulic conductivity in the backfilled materials ranged from $1 \times 10^{-6}$ to $1 \times 10^{-8}$ cm/sec. It has also been demonstrated that many heavy metals, which are high in concentration in mine runoff, such as iron, cadmium, lead, arsenic, and others, are reduced when water flows through encapsulated CCR rather than through the exposed mine workings. There are a few sites where certain constituents have higher concentrations after flow through encapsulated CCR, including boron, arsenic, nitrate and nitrite, sulfate, and chloride. Nevertheless, the flow rate at these sites may be reduced so greatly through void
reduction that the mass loading of these constituents could be considered more relevant 
data regarding the change in water quality.

Beyond water quality changes and overall improvements, subsidence mitigation and 
hydrological improvements can be made at mine sites through use of CCR backfill. As 
discussed, underground mine voids contribute to a lack of surface stability and bearing 
capacity and pose subsidence risk; voids can also generate methane and pose mine 
fire risks. Filling of these mine voids with structural, flowable backfill decreases the risk 
of mine fire by reducing the interaction between the mined rock face with air flow. 
Additionally, these materials exhibit excellent shear strength depending on the overall 
composition and percentage of fly ash used. Concrete with high rates of ash addition 
(50% fly ash) have been demonstrated to exhibit greater unconfined compressive 
strength results than a typical concrete mix with no ash addition. Importantly for the 
uses noted herein, grout strengths far below those of concrete will often be acceptable. 
Therefore, a proportioning-based analysis can be used to develop an optimally cost-
effective formulation that balances strength requirements with materials costs.

Other uses of CCR backfill may be employed at the sites once the transport and 
infrastructure are established. Grading improvements at the ground surface can be 
constructed using CCR concrete materials to slow water flow or direct run off toward 
particular portions of the site, and to dedicated discharge points. Utilities can use these 
same concepts during site improvements and pond closures closer to the point of CCR 
generation.

ASH IN USE: CONSTRUCTION METHODOLOGIES AND CONSIDERATIONS

The use of CCR encapsulated materials for mine reclamation will differ greatly, 
according to placement and overall closure objectives at each site. There are two major 
reclamation concepts that will be highlighted here to show the contrast in the 
implementation of these backfill materials and to show the possibilities of replacement 
of aggregates, capping materials and flowable fill by CCR materials for potentially 
reduced costs and enhanced material properties.

Transportation

The single largest challenge to use of CCR materials as backfill for mine sites is the 
potential distance between coal generation facilities and mines requiring reclamation. In 
some cases, the transportation cost of importing CCR materials to the mine site may be 
prohibitively expensive. However, in other cases, rail lines may be used effectively to 
haul CCR in large quantities. Some coal plants have transported CCR materials to the 
coal mine that generates their coal; the rail cars that ship coal to the plant return to the 
mine loaded with CCR materials for use as backfill.

Underground Mine Void Backfilling with Flowable Fill
Underground mines often represent a network of tunnels or a network of rooms and pillars, some close to the ground surface and others hundreds of feet in the subsurface. Filling of these voids to limit generation of acid mine drainage and to reduce risks of subsidence or mine fires necessarily requires the filling of the maximum amount of volume possible, even if there is a specific area targeted for backfill. CCR grouts are the best materials for this application as the mixture developed using some combination of CCR, lime, Portland cement, and/or bentonite (as appropriate) and water is flowable and can be produced by a batch plant. The grout developed can then be transported overland to the point of injection where it can be delivered via a tremie pipe to the subsurface mine voids. The tremie pipe can be manipulated to various depths such that the deepest backfill point is targeted first and as the void fills, the tremie pipe is raised and the risk of bridging of materials over voids is reduced. Previous experience has demonstrated a high degree of filling and dispersion when the grout is properly configured and the mine void distribution is relatively well understood. This concept is demonstrated in Figures 2 and 3.

FIGURE 2 – Existing Conditions at Underground Abandoned Mine Land Sites
Surface Mine Reclamation through Creation of a CCR Impoundment

Where surface coal mines, hard rock mines, and active mines have created benched open pits, permitting of a CCR impoundment may be possible which would capitalize on a pit configuration that is already excavated, as conceptually shown in Figures 4 and 5. The benched surface of the open pit would need to be bridged with overburden or another backfill material to create inner slopes and subgrade suitable for the liner system that would be advocated to meet Subtitle D criteria. This covering of the mined open pit surface would have the added benefit of mitigating acid mine generation.

Once the landfill base liner is created, CCR materials could be transported to the mine site and placed in the impoundment as they are currently being placed in newly constructed and permitted landfills. Once filled, the pit would be capped and revegetated. The mine operator would have the added benefit of reducing the value of the reclamation bond for the mine site.
FIGURE 4 – Active Surface Coal Mine Absent Reclamation
Utilities and state regulators interested in utilizing CCR materials for mining reclamation projects should work together to consider potential partnerships, as the outcomes for both parties will depend on the objectives, schedule prerogatives and budget limitations of each. As mentioned previously, selective beneficial re-use may have broad-based environmental and financial benefits.

Active mine sites may have more limitations placed on the acceptance of backfill materials. Many have volumetric limitations in the form of tonnage per year that they are willing to or may be able to accept. Still others, may have ongoing operations that conflict with certain design possibilities and therefore the applicability of CCR utilization for reclamation may be more isolated in scope. Each partnership between the mine operators and/or state regulators overseeing mine reclamation, and the utility company and their contractors supplying the CCR and backfill materials, will be a unique relationship that collaborates to achieve the objectives of each party for their mutual benefit.
The necessary steps to evaluate the applicability of CCR backfill materials for mining reclamation will include:

- Analysis of geotechnical and geochemical properties of the CCR materials (fly ash, bottom ash, and/or FGD materials, as well structural properties of CCR grouts and other construction materials)
- Evaluation of existing abandoned and/or active mine sites which would require reclamation
- Construction estimating of overall cost to the coal plant for beneficial reuse, possibly combined with overall cost to mine operator and/or state regulator for reclamation
- Bench scale leachate testing to validate beneficial re-use standards can be met
- Permit level design and application
- Final design and implementation

CONCLUSION

The use of CCR materials as backfill primarily replaces the need for native aggregate materials by satisfying the same requirements for permeability, strength, and mitigation of acid mine drainage. CCR materials can replace aggregate in concrete to reduce costs of manufacturing and retain similar, if not enhanced material properties for mining reclamation. Similar considerations should be made by utilities during their closure planning, as construction materials used for closure can similarly be replaced by CCR materials which are present in abundance without a need for import or for significant materials processing. The economic drivers behind both mining reclamation projects and CCR management projects, whether they be closure or ongoing management, will dictate the alternative approaches that are desirable and feasible for implementation.

REFERENCES