# Utilization of Fly-Ash in the Backfilling of Void in Underground Mines

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**Abstract.** Coal-fired thermal power plants worldwide are encountering significant challenges in handling and disposing of the ash generated during the combustion process. The problem is further exacerbated by the high ash content (30–52%) present in Indian coal. Thermal power plants face major concerns regarding the safe disposal of coal ash and the need for large storage areas. Consequently, efforts have been made to find alternative uses for the ash, rather than simply dumping it in nearby ash ponds. One promising approach involves utilizing underground mine voids to accommodate the bulk of the fly ash. Underground mine spaces have the greatest potential for storing fly ash in large quantities compared to other possible applications. The process involves using filling materials to reinforce the surrounding rock and provide support to the overlying strata, thereby reducing surface subsidence. This paper presents a study conducted in this context, focusing on the bulk utilization of fly ash in backfilling applications. The research aimed to find viable solutions for effectively utilizing fly ash, thereby addressing the challenges faced by coal-based thermal power plants in managing and disposing of this by-product. This innovative approach presents an encouraging solution for sustainable mining practices and minimizing the environmental impact associated with coal extraction.

**Keywords:** Fly ash · Underground Mines · Mine Void · Subsidence and Backfilling

## 1 Introduction

Growth of the any nation depends on the availability of energy resources. Country like India, where 65% of population are below 35 age group, automatically the necessity of energy is too high to meet the aspiration of young generation. Due to this reason, advancement and introduction of emerging technology in energy sector still not meeting the presence need of the country. Therefore, 70% of energy requirement is achieved by


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coal based thermal power plant. It is seen that all over the country, coal have 30–52% ash content (Dutta et al., 2009). This tremendous amount of ash produce from the thermal power plant are meeting severe problems of handling, management and disposal. Safe dumping of the coal ash and the large storage area required are major concerns of thermal power plants. Hence current requirement of coal based thermal power plat is to identify the alternative to disposed fly ask in safe, economical without occupied in large space.

Majority of the coal and other valuable minerals deposit present deep inside the mother earth. However, most of the coal mines extracted the coal through opencast mining method rather than underground mining method in India due to major safety concerns (Kashi et al., 2023). Currently in 2021–22, 95% of production is through opencast mining, whereas, previously 97% was done through it in 2020–21 (Kashi et al., 2020). Also, most of the coking coal are present too deep inside the earth i.e. below 500 m depth. Still, India is the 3$^{rd}$ largest producer of coal, but although 80% of coking coal is imported from other countries. Innovation and new technology will completely changing the scenario of current mining methods and empowering the mining industry to extract minerals through underground operation. Day-by-day huge mechanisation and application of portable safety related machines are enhancing the working condition of underground mines. In underground, Lots of the area is left empty and void due to extraction of coal and minerals from there. This will create subsidence problem and not only affect the upper surface of ground, but also destabilise the working roof strata. Those reduce production by wasting of coal left to control strata and enhance overall cost of production (Goswami and Mahanta, 2007).

To overcome from the above such situations, backfilling of the goaf made through excavation of coal from mined area is mandatory. Owing to technical and environmental reasons, backfilling is practiced in many countries such as China, Poland, USA etc. (Sivapullaiah et al., 1995). The utilization of filling materials serves the purpose of reinforcing the caving rock and providing support to the overlying strata, thereby mitigating the rate of surface subsidence. In mining operations where appropriate support measures are not implemented, the broken roof can experience failure and collapse. This poses a challenge for conducting continuous backfill mining in such conditions using conventional mining techniques. This voids are backfilled with materials such as sand, waste from coal preparation plant and waste rocks (Fig. 1).

A review of existing literature indicates that hydraulic sand stowing is a widely employed technique in underground coal mines across the globe to mitigate surface subsidence. However, the mining industry in India is currently facing a significant scarcity of river bed sand due to its increasing demand in civil engineering projects. Consequently, numerous underground coal mines remain unfilled after coal extraction, resulting in surface subsidence issues.

To address this challenge, the mining industry has been actively seeking an alternative filling material that is readily available near the mine site and cost-effective. Fly ash has emerged as a potential solution to meet these requirements. Fly ash is a by-product of coal combustion in thermal power plants and occupies considerable land space in the form of ash ponds near power plants. These ash ponds contribute to various environmental issues and ecological imbalances. By exploring the use of fly ash as a filling material, the mining industry aims to minimize surface subsidence in underground coal mines while

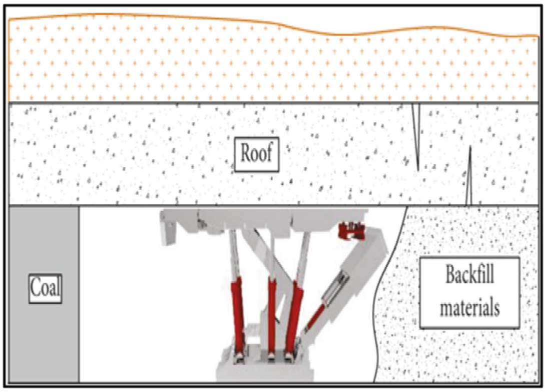


**Fig. 1.** Visualization of backfilling of underground longwall mine void area

also addressing the environmental concerns associated with the accumulation of fly ash in ash ponds. This approach offers the potential to repurpose fly ash, transforming it from a waste product into a valuable resource for mine filling applications.

The effective and comprehensive utilization of the vast quantities of idle fly ash has become a substantial task for coal based plant authorities. Fly ash possesses various geotechnical applications, including its use in bricks, cement, embankment construction, aggregates, fill material (Banita & Mishra, 2011). Several fruitful efforts have been made to utilize fly ash both solo and in combination with cement, lime or gypsum (Mishra & Rao, 2006). It has been recognized that the bulk utilization of fly ash in mine filling applications holds significant potential. These studies have shown that the utility of fly ash can be upgraded by adding lime.

However, the aforementioned application areas have limitations when it comes to cooperative fly ash in large quantities. Filling of mine void presents a crucial and emerging zone for heavy deployment, provided that the features of fly ash can be appropriately improved. To ensure active consumption in this context, the material should be chemically non-reactive and free from burnable substance that could pose a risk of spontaneous heating and fire in coal mines. Additionally, particle size and structure, density, porosity, water content, pH, and other factors play crucial roles in the hydraulic transportation of fly ash to mine void filling areas.

Conducting studies in this field would be immensely helpful in making informed decisions regarding the selection of materials for filling underground mine cavities and developing methodologies to address finer details. Furthermore, these investigations could provide insights and supplement similar applications in various other areas.

## 2 Materials and Method

### 2.1 Fly Ash

Fly ash is typically the resultant by-product of the combustion of pulverized coal in thermal power plants. It is commonly described as a finely-distributed amorphous aluminosilicate with varying amounts of calcium. The residue, or fly ash, originates from the burning region of the boiler, where it is carried away by the flue gases and subsequently collected using either mechanical or electrostatic separators.

Fly ash exhibits pozzolanic properties, meaning it can react with calcium hydroxide in the presence of water to form cementitious compounds. It is composed primarily of oxides such as $SiO_2$ (silicon dioxide), $Al_2O_3$ (aluminum oxide), $Fe_2O_3$ (iron oxide), CaO (calcium oxide), $K_2O$ (potassium oxide), and $TiO_2$ (titanium dioxide) (Table 1) (Ahmaruzzaman, 2010). These components can vary in concentration depending on the specific composition of the coal and the combustion process (Table 2).

Different classifications of fly ash have been suggested based on various factors such as constituent materials, characteristics, application, and chemical properties. One commonly used classification is based on the ASTM Specification (ASTM C 618, 1995), which categorizes fly ash primarily into two types: F-Type and C-Type fly ash.

The F-Type fly ash designation refers to fly ash with pozzolanic properties, meaning it can react with calcium hydroxide in the presence of water to form cementitious compounds. This type of fly ash is typically derived from burning bituminous or sub-bituminous coals. On the other hand, C-Type fly ash encompasses both pozzolanic and cementitious fly ashes (Naik & Mishra, 2018). This type of fly ash generally originates from burning lignite or sub-bituminous coals and exhibits cementitious properties, which allows it to contribute to the strength and durability of concrete when used as a supplementary cementitious material.

**Table 1.** Chemical Characteristics of Fly Ash

| Constituents | Percentage (%) | Constituents | Percentage (%) |
|---|---|---|---|
| Carbon | 2.1 | $P_2O_5$ | 0.17 |
| Volatile Matter | 0.147 | $SO_3$ | 0.24 |
| $Fe_2O_3$ | 8.83 | $K_2O$ | 0.79 |
| MgO | 0.84 | CaO | 1.11 |
| $Al2O_3$ | 27.73 | $Na_2$ | 0.14 |
| $SiO_2$ | 58.9 | $TiO_2$ | 2.09 |

**Table 2.** Physical Characteristics of Fly Ash

| Parameters | Value |
|---|---|
| Colour | Light Gary |
| Dry Density (kg/m$^3$) | 1380 |
| Specific Gravity | 2.54 |
| Optimum Moisture Content (%) | 38.7 |
| Permeability (m/sec) | (3.5–3.7) * $10^{-6}$ |
| Liquid Limit (%) | 40.89 |
| Plastic Limit (%) | Non-Plastic |

## 2.2 Lime

Calcium oxide, also known as quicklime or burnt lime, is a highly utilized chemical compound with various applications. It appears as a white, caustic, alkaline, and crystalline solid at room temperature. Quicklime and its derived materials continue to be widely employed in construction and engineering due to their valuable properties. These materials include limestone products, cement, concrete, and mortar.

The primary source materials for quicklime production are rocks and minerals such as limestone or chalk, which primarily consist of calcium carbonate (Table 3) (Mishra & Das, 2010). Lime serves as a substance that hardens and binds other materials together, making it essential in construction processes. One of its primary applications is as a binder for floors and plaster coatings on walls. The versatile nature of quicklime makes it a valuable component in various industries, ranging from construction to chemical manufacturing.

Normal mine water is used for this purpose.

**Table 3.** Chemical Composition of Lime

| Constituents | Percentage (%) |
|---|---|
| Minimum Array (Acidimetric) | 95.0 |
| Maximum Limits of Impurities | |
| Chloride (Cl) | 0.1 |
| Sulphate ($SO_4$) | 0.5 |
| Iron (Fe) | 0.1 |
| Lead (Pb) | 0.02 |

### 2.3 Methods of Mine Backfilling

The backfilling of underground mine voids can be accomplished using a slurry made of fly ash and lime. Two methods commonly employed involve the use of fly-ash slurry. The slurry is created by mixing fly ash with mine water. The flow chart illustrating the process of the slurry-based backfilling method is detailed in Fig. 2.

In the hydraulic stowing method, which is widely practiced for void filling, the fly ash and lime mixture is mixed with water at the surface (Naik & Mishra, 2018). This mixture is then allowed to flow under gravity or with the aid of pumps into the underground void to be filled. It is important to note that the fine particles of fly ash possess pozzolanic properties, which can potentially clog the pores of the soil or aquifers, reducing their permeability. Additionally, any trace elements present in the leachate from the voids are likely to undergo chemical adsorption reactions with clay materials present in the soil, which can restrict their transport.

Any excess water present in the slurry will drain out to the surface, and this water can be reused in the production of the fly ash slurry. After the slurry is deposited, it begins to settle, and within approximately one day, it solidifies and becomes integrated with the surrounding strata. This solidified slurry provides effective roof support and enhances production within the mine.

Overall, the use of fly ash slurry as a backfilling method offers advantages such as improved structural support, reduced permeability, and the potential for reusing water resources. It provides a practical and efficient solution for filling underground mine voids.

## 3 Results and Discussion

### 3.1 Filling of Mine Void with Fly Ash Lime Slurry Through Pump

The process of backfilling underground mine voids involves three key steps: stirring, pumping, and filling. During the stirring phase, water and fly ash are mixed thoroughly in a specific proportion, typically 8 parts water to 10 parts fly ash by mass. This mixing takes place in a designated mixer, ensuring the components are well blended to form a homogeneous fly-ash slurry.

Once the slurry is prepared, the pumping stage begins. The fly-ash slurry is directed to the hopper of a concrete pump, which serves as the transportation mechanism. The slurry is then pumped from the hopper through a filling pipe, facilitating its transfer to the working face located underground. This process utilizes the concrete pump's pressure to ensure the slurry reaches the desired location efficiently.

Finally, the filling stage involves delivering the slurry to the goaf, which refers to the underground void or space to be filled. This is achieved through the use of both the filling pipe and branch filling pipes associated with the working face. The filling pipe is laid along the tendency or trend of the working face, and its length typically matches the extent of the working face itself. The branch filling pipes, on the other hand, are laid parallel to the trend of the working face, with their lengths varying between 10 to 20 m. The slurry is carried through these pipes, ultimately reaching and filling the targeted goaf area.

By following these steps, stirring the fly ash with water, pumping the resulting slurry using a concrete pump and filling pipe, and finally delivering the slurry to the goaf through filling and branch filling pipes – the backfilling process can be carried out effectively, ensuring proper utilization of the fly ash and achieving the desired filling objectives within the underground mine voids.

The stirring subsystem, as depicted in Fig. 2, consists of three main components: the fly-ash bin, screw feeder, and mixer (Kumar, 2010). The fly-ash bin serves as a storage unit for stockpiling fly ash. From the fly-ash bin, the fly ash is transported to the mixer using a screw feeder. Inside the mixer, the fly ash is thoroughly mixed with mine water, resulting in the formation of a fly-ash slurry.

In summary, this system facilitates the mixing of fly ash with mine water to create a fly-ash slurry, which is then conveyed to a distant filling operational side using a pump and a network of filling pipes, including branch filling pipes. This allows for efficient and controlled deposition of the fly-ash slurry at the designated working face.

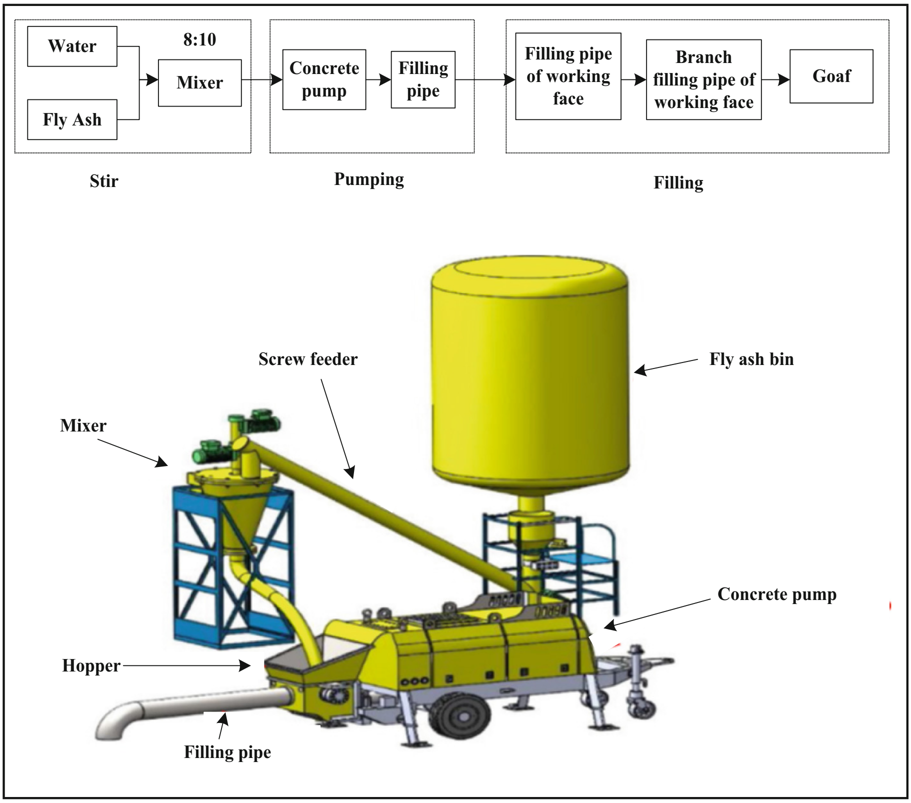


**Fig. 2.** Flow chart of the process of backfilling in a underground mine's void

## 4 Conclusions

After analyzing and researching the merits and drawbacks of existing filling materials, this paper introduces a novel filling material called fly-ash lime water slurry. The primary objective of employing this material is to exercise control over surface subsidence in mining operations while also facilitating the complete extraction of coal from barrier pillars.

The study presents the results obtained from a practical field application of the proposed technique. The approach involves the transportation of fly-ash slurry through a pipeline and subsequent grouting for backfilling purposes. The results demonstrate that this method effectively controls the movement of the overlying strata, leading to a significant reduction in surface subsidence.

The utilization of fly-ash lime water slurry as a filling material offers several advantages. It not only addresses the issue of surface subsidence but also enables the extraction of coal from previously inaccessible barrier pillars. This innovative approach presents a promising solution for sustainable mining practices and minimizing the environmental impact associated with coal extraction. The wide range of applications for fly ash underscores its potential as a valuable resource with numerous benefits. From mine void filling to civil road & embankments construction, cement manufacturing, and brick production, fly ash presents a sustainable and cost-effective solution in various sectors.

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