

## Some Considerations of Highwall Mining Systems in Coal Mines

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**ABSTRACT:** The purpose of the highwall mining system is to extract coal with an auger machine or a continuous miner from exposed seams at the base of open pit or strip operations. The major factors in the highwall mining system are coal recovery and the stability of the highwall. A large amount of coal remains isolated and undeveloped as pillars due to previous indiscriminate mining operations performed by the use of the auger or the continuous miner. Therefore, it is necessary to increase the coal extraction ratio, and to reduce the threat of failure of the pillars and highwall and reduce damage caused by subsidence at the surface. This paper describes the background of the study, reviews the highwall mining system and discusses some considerations in the application of highwall mining systems with a view to increasing the extraction ratio and keeping the highwall stable.

### 1 INTRODUCTION

Final highwalls in open pit coal mines can form a starting point for other mining methods, such as highwall or underground mining. In its basic application, highwall mining is a technique utilized after the open pit portion of a reserve has been mined, sometimes prior to the introduction of underground mining (Seib, 1993).

However, a large amount of coal tends to remain isolated and undeveloped as pillars due to previous indiscriminate mining operations performed by the use of an auger machine or a continuous miner. Moreover, highwall mining may cause highwall instability and surface subsidence.

In this study, the background of the study is described, then the highwall mining system is reviewed, and finally, some considerations are discussed with a view to increasing the extraction ratio and maintaining the stability of the highwall.

### 2 BACKGROUND

Indonesia produces over 70 million tons of clean coal annually and is the second largest coal exporter to Japan, with about 12 million tons annually. 99% of the total production of coal is from open pit mines. It is anticipated that more open pit mines will be developed and more coal will be mined underground in order to fulfill the great demand for

coal in Indonesia and the rest of the world.

In order to maintain its confidence as the largest coal importer in the world, Japan has started a 'five-year plan for coal technology transfer'. Under the plan, Japanese coal technology will be transferred to coal-producing countries, especially Indonesia.

In the academic field, joint research work has, since 1998, been conducted by Kyushu University, Japan, Institute of Technology Bandung (ITB) and the Indonesian Institute of Sciences-LIPI at Ombilin Coal Mine, Indonesia. This work is directed primarily towards the optimal support system and the development of optimal underground mining systems in Indonesia. Some findings of the joint research project have already been reported (Anwar et al., 1998, 1999a, b; Matsui et al., 1999a; Kramadibrata et al., 2000; Matsui et al., 2000a, b).

Because almost all the coal is extracted from open pit mines in Indonesia, there are many sites where mining operations have developed long highwalls that have been abandoned due to the economics of the day. Mining operations have been transferred to lower stripping ratio blocks of coal or overlying seams. In some cases, coal lies buried beneath spoil heaps or is covered with mud and water. It is estimated that there is a great deal of coal beneath both abandoned and working highwalls. In light of this, it seems to be worth pursuing the possibility of the introduction of highwall mining systems into Indonesian open pit mines.

### 3 HIGHWALL MINING SYSTEMS

A highwall mining system extracts coal from exposed seams at the base of open pit or strip operations as shown in Figure 1. Auger machines and continuous miners are suited to all applications where a seam of coal has been exposed as a result of open pit mining. Seams as thin as 1 meter can be highwall mined depending on the choice of system.

Final highwalls in open pit coal mines can form a starting point for other mining methods, such as highwall or underground mining. In its basic application, highwall mining is a technique utilized after the open pit portion of a reserve has been mined, sometimes prior to the introduction of underground mining.

Surface reclamation and/or rehabilitation costs after highwall mining are minimized due to the small bench required to gain access to the coal seam.

The narrow bench needed to operate the highwall mining system is not only economically attractive, but also offers minimal disturbance to the surrounding land, making mining possible on relatively small properties. The highwall mining system is extremely mobile and can be moved from pit to pit in a matter of hours, or from one mine to another in a day or two.

Many coal seams that are presently uneconomical

or technically unsuited to conventional mining techniques can be recovered using the highwall mining system.

#### 3A Auger Mining

Augers became part of the contour-mining cycle in hilly areas in the Appalachian coalfields during the 1950s. They allowed the recovery of additional coal that would have otherwise been left. They began growing in size and power in the 1960s, so that by the early 1970s some were being built with a diameter of as large as 2.1 m and were capable of drilling up to 60 m into the coal seam. New auger designs have boosted the use of augering. Some new designs are capable of boring almost square holes while others can back-ream the holes to pull out a higher percentage of coal.

The auger system works at right angles to the highwall, driving a 5-5-m long cutting head into the coal seam, as shown in Figure 2. The motion of the cutting process carries the coal back to the collar of the excavation.

The auger machine can excavate holes over 100 m long and 1.0 m in diameter and greater in the coal seams from highwalls, depending on the method of application. Single or multiple pass operations are possible.

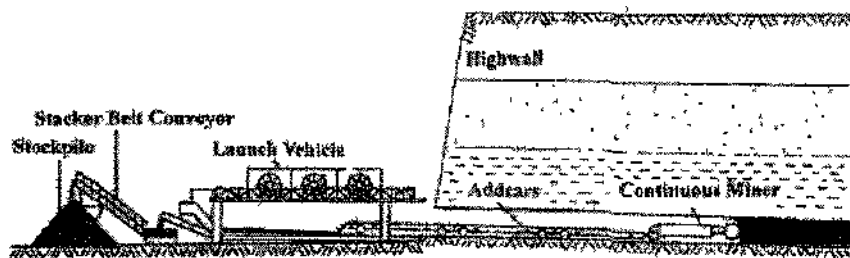


Figure 1. Highwall mining system



Figure 2. Auger mining

In Australia, about 9000 tons of coal was produced by a three-person crew in a 12-hour-shift 5-day week. Its best performance is 13,200 tons.

The auger is more maneuverable than the continuous miner and can be applied when shorter lengths of highwall are present. It is also suitable for recovering open pit end walls and major pillars of coal remaining after continuous miner operation.

The auger cutting head drives directly from the auger into the coal seam. Additional 5.5-m long flights are added as the hole deepens. This process continues until the final depth of the auger hole is reached.

Once each flight is in place, tractive effort is provided by hydraulic rams. Each auger flight is connected via a latch pin assembly that operates by remote control from the operator's climate-controlled cabin. As the coal is extracted from the excavation, a side conveyor advances the coal onto a stacker belt for stockpiling.

The auger flights are retracted from the hole by reversing the mining sequence.

Operators are sheltered by a full-length Falling Objects Protective Structure (FOPS). They are also protected from possible methane initiation by a gas inactivation system. The system diffuses methane gas by injecting oxygen-starved air. This process provides a safer working environment and promotes greater productivity, since operations are able to continue in known gas areas.

A new-generation, higher-power auger is being designed and built, which will be more effective because of the addition of various controls. This new auger, however, does not overcome the inherent problems associated with augers, particularly that of diminishing power with increased augering depth. Augers also suffer from increasing size degradation with depth, a fixed cutting height and certain other operational attributes that diminish the percentage of coal actually recovered. Neither do augers have the ability to negotiate dips and rolls in the seam because of the rigid structure of the auger flights.

### 3.2 Continuous Highwall Mining (CHM)

#### 3.2.1 Addcar System

The Addcar system consists of a continuous miner, launch vehicle, 30 conveyor belt cars (addcars), a stacker conveyor, and two loaders, as shown in Figures 1, 3 and 4.

The continuous miner is positioned at right angles to the highwall on the launch vehicle. Addcars are progressively linked from the launch vehicle to extract the coal from the advancing continuous miner. The system can currently handle seams ranging from as low as 0.97 m to as high as 5.2 m in thickness.

One week of production by a five-person crew

(four crews) can produce between 20,000 and 30,000 tons of coal.

The addcar system provides a cost-effective and safe means of extracting coal from final open pit highwalls and purpose-built trenches, and is ideally suited to applications that have 500 m or more of exposed highwall.

The continuous miner is remote controlled and will reach up to 350 m into the wall. The addcars facilitate a continuous flow of coal from the cutting head of the continuous miner to the launch vehicle belly belt and stacker conveyor. Hydraulically powered push arms provide thrust in addition to the tractive effort of the continuous miner.

The removal of the system from a completed hole is simply the mining sequence in reverse.

A five-person crew operates the entire system under the protection of a full-length Falling Object Protective Structure (FOPS), and it is also sheltered by frontal blast doors. Methane monitors mounted on the continuous miner provide the operator with constant information for safe mining operations.

The system is operated from a comfortable air-conditioned cab located on the rear of the launch vehicle. Up to six remote monitors provide the operator with the visual information necessary to control the system. The quality of pictures obtained from the continuous miner is preserved by automatic jet washing of the camera boxes.

#### 3.2.2 Archveyor System

The system consists of a continuous miner, chain conveyor (Archveyor conveyor) and a loadout vehicle. The loadout vehicle contains an onboard substation for power distribution and control of all three main system components.

The continuous miner mines in a cyclical fashion into the coal seam of the highwall. As the coal is mined, it is conveyed by the miner to the Archveyor conveyor. The Archveyor carries the coal to the loadout vehicle. The loadout vehicle receives the coal from the Archveyor and moves it from ground level to a height that is suitable for loading into open cut, mine-type haul trucks. The system requires just two employees per shift to safely mine coal from exposed highwalls.

One week of production will produce over 30,000 tons of coal depending on the strata and mining condition.

The current available length of the chain conveyor is 350 m, being variable in excess of 350 m. As the miner advances, the Archveyor advances to the miner once every 1.85 m. The Archveyor does this by lowering itself to the ground and bringing the return side conveyor chain in contact with the floor. The Archveyor conveyor chain is then reversed, which gives tractive effort to the complete length of

die chain conveyor system. The Archveyor advances to the miner in the manner of a large crawler truck. Thus, the Archveyor conveyor chain performs a dual role, by conveying coal as well as advancing the chain conveyor itself.

The multiple-drive motors (one every 7.5 m) make up the primary electrical drive components of the chain conveyor system. All the conveyor motors are started together to move the chain conveyor system. They are reversed and started together again

to convey coal to the loadout vehicle. The loadout vehicle advances with the conveyor every other chain conveyor advance. This process is continually repeated until the full extent of mining in each particular hole is complete.

A variety of sensors keep the miner in the seam automatically. The sensors include a roof and floor passive gamma detector system, multiple inclinometers, a ring laser gyroscope, and a programmable logic controller.

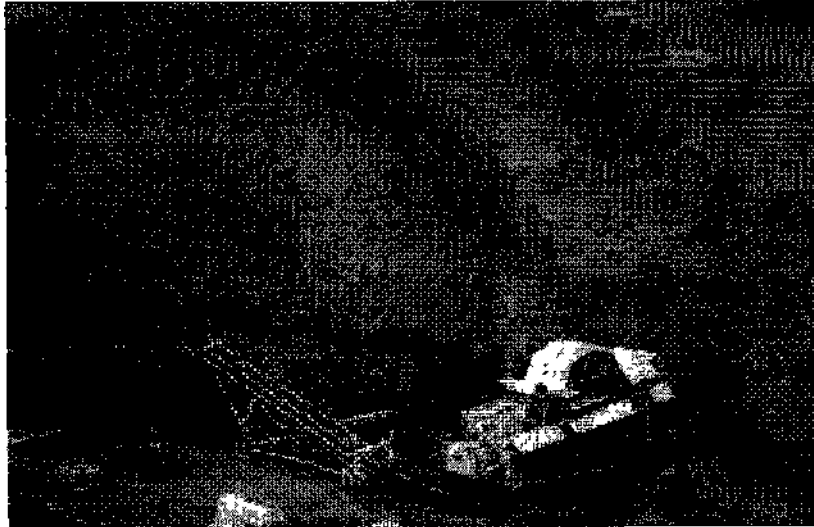


Figure 3 Addcar system.



Figure 4 Loader carrying an Addcar

These components are of flameproof or intrinsically safe construction, or are located inside flameproof enclosures.

This mining process is highly automated and controlled through the use of a programmable logic control (PLC) system. PLC technology has been m

use in processing and manufacturing facilities for the last two decades, and it has been used on underground coal mine conveyors and longwall systems for the last decade as well.

Operators are sheltered by a full length FOPS. They are also protected from possible methane initiation by a gas inactivation system. The system diffuses methane gas by injecting oxygen-starved air. This process provides a safer working environment and promotes greater productivity, since operations are able to continue in known gas areas.

The system can be used in underground mines and is more productive and safer, with a lower cost than other mining methods.

#### 4 OPERATIONAL AND GEOTECHNICAL CONSIDERATIONS

Highwall mining improves mining operations due to its safe mining system. The highwalls are generally along the strike of the seam, meaning that if the seams are extracted perpendicular to the highwall, as is normally the case, mining will be along the dip of the coal seam. Highwall mining in Australia has been carried out on seam dips ranging from 2-15°. Retraction is faster on lower grades, and therefore productivity is affected by the seam dip. However, it is difficult or almost impossible to apply the system in steeper dip coal seams, over 15°. Therefore, another strand of system development is aimed at coal seams in the 16-25° dip range. There are currently no mining methods available for mining seams in this dip range beyond their final economic highwall.

Use of an effective dip mining method with the basic highwall mining system is an alternative for steep coal seams. The machine is positioned at some angle off the perpendicular to the highwall to extract the coal with an effective dip within the limit of the machine.

Roof conditions have had a great influence on machine performance in certain seams. The rectangular geometry of the current excavations resulted from the lack of availability of suitable machines to mine more favorable shapes. Field trials of a machine that will form an elliptical excavation with a short exposed roof span are now being conducted.

Mine water is another big problem. Any small amount of water tends to collect at the face in inclined seam excavations, interfering with excavation work and decreasing the stability of the excavation. Stable loading and haulage operations should be established even with the existence of water in the face. It is necessary to control the water rush-in into the face on rainy days or during the

rainy season in highwall mining, especially in Indonesia. Moreover, some coal measure rocks such as shale, siltstone and mudstone show excessive slaking behavior, leading to a severe deterioration of their properties. The immediate roof tends to fall easily and the machine also tends to sink or slip on the softened floor. These problems make the controlling system difficult.

#### 5 BACKFILLING SYSTEM

In highwall mining systems, a large amount of coal tends to remain isolated and undeveloped as pillars due to previous indiscriminate mining operations. Moreover, highwall mining causes highwall instability and surface subsidence. Specifically, the situation is more complicated in Uick seams. In order to cope with these problems, backfilling must be considered in a highwall mining system. Some considerations regarding backfilling in highwall mining have already been reported (Matsui et al., 2000b).

Figure 5 shows the failure development around openings with a narrow pillar in highwall mining. With a narrow pillar, the openings show less stability and the pillars fail much more severely than wide pillars. This situation leads to unstable work conditions, and in some cases, the cutting machine can be caught in the opening, making it impossible to withdraw.

Figure 6 shows the failure development around openings with backfilling. It is clear that backfilling helps the openings remain stable when compared to the situation which is shown in Figure 5.

Backfilling in underground mines is not a revolutionary concept. Waste rocks have been used throughout the world for many years as backfilling material to provide additional support to underground excavations in mines. Recently, due to the lack of dumping sites, the use of backfill for regional and local support has received increased attention in the mining industry.

According to previous research work (Afrouz, 1994), backfilling offers the following benefits to underground coal mines:

- 1) Fills the excavated areas, promoting better support and ground control.
- 2) Provides better environmental control of the waste rocks and coal preparation plant wastes.
- 3) Increases coal recovery, especially in room and pillar mining and highwall mining systems.
- 4) Reduces ventilation short-circuiting between adjacent mining sites.
- 5) Reduces cost of waste transportation to the mine surface dumping sites and tailing ponds, thus reducing the cost of associated up-keep and monitoring of these facilities.

The required strength of the backfill depends on the strata and mining conditions: cover depth, rock type and properties, mining method, etc. In a shallow mine, the required strength is not as critical when compared to that for a deep mine. According to research work done in South Africa, backfilling shallow underground room and pillar mines with pulverized flyash slurry could significantly improve the mine operating conditions by providing improved roof support and an increased extraction ratio (Wagner et al., 1979). The research also suggests that the complete filling of the rooms, up to roof level, is not necessary for improved roof control. Filling up to 70% of the pillar height provided adequate confinement, which constrained the lateral expansion of the pillar under concentrated compressive stresses. Moreover, by providing confinement to the pillars, thick coal seams have been successfully mined with a subsequent reduction of pillar height to width ratio and have

improved the load-bearing capacity of the pillars.

Backfilling materials that are of concern to the mining industry can be broadly classified in the following three categories (Matsui et al., 1999b):

- 1) Waste originating from coal mines.
- 2) Waste originating from coal-burning power plants.
- 3) Waste originating from other industries.

In the USA, increased opposition from environmental groups is severely restricting the operation and planning of large-scale surface mines. Some projects of mountaintop removal mining have had to be cancelled or downsized. In these situations, as discussed in the previous section, the highwall mining system would be applicable and useful for the protection of the environment and reclamation. Backfilling would increase the coal extraction ratio, keep the pillars and the highwall stable and control the subsidence at the surface.

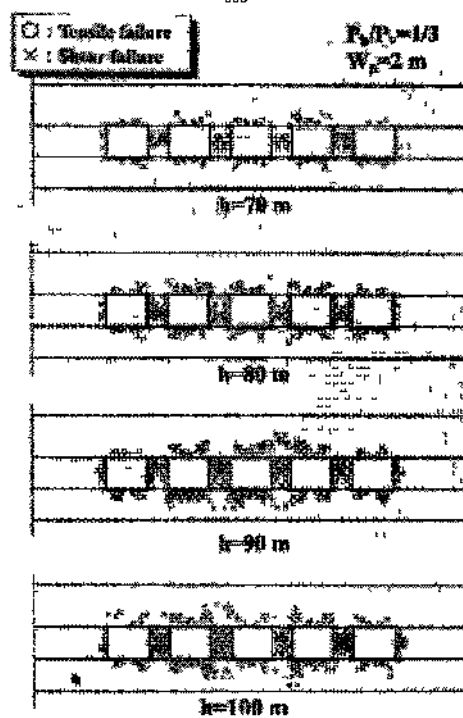


Figure 5 Failure development around the openings under the different initial stresses

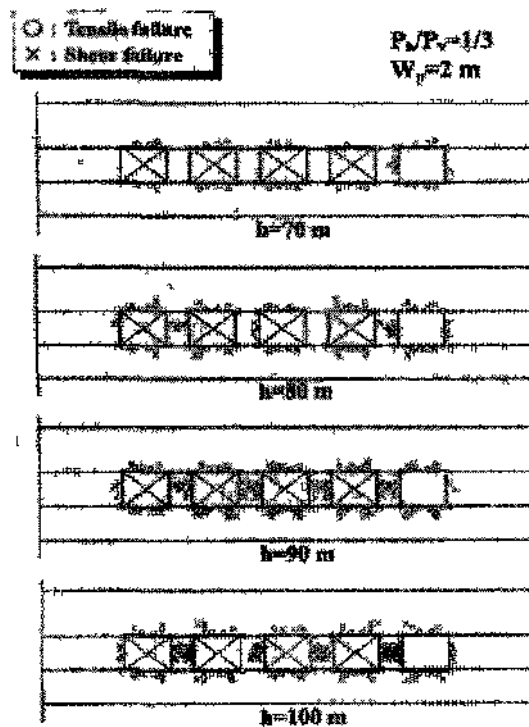


Figure 6 Failure development around the openings with backfilling

## 6 CONCLUSIONS

Highwall mining systems can sometimes be the final mining method used in open pit mines, or they can serve as a means of transition, with low capital cost, from surface mining to underground mining

Backfilling in the highwall mining system not only increases the coal extraction ratio and highwall stability, but also contributes to the protection of the environment around the mines. However, the optimal backfilling system needs more intensive investigation, because there are many factors which need to be considered

The mining system also has to be improved so as to cope with steeper coal seams and water problems at the face in order to increase the extraction ratio and to maintain highwall stability

The highwall mining system will be introduced into Indonesian open pit mines in order to improve productivity and to reduce environmental problems

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