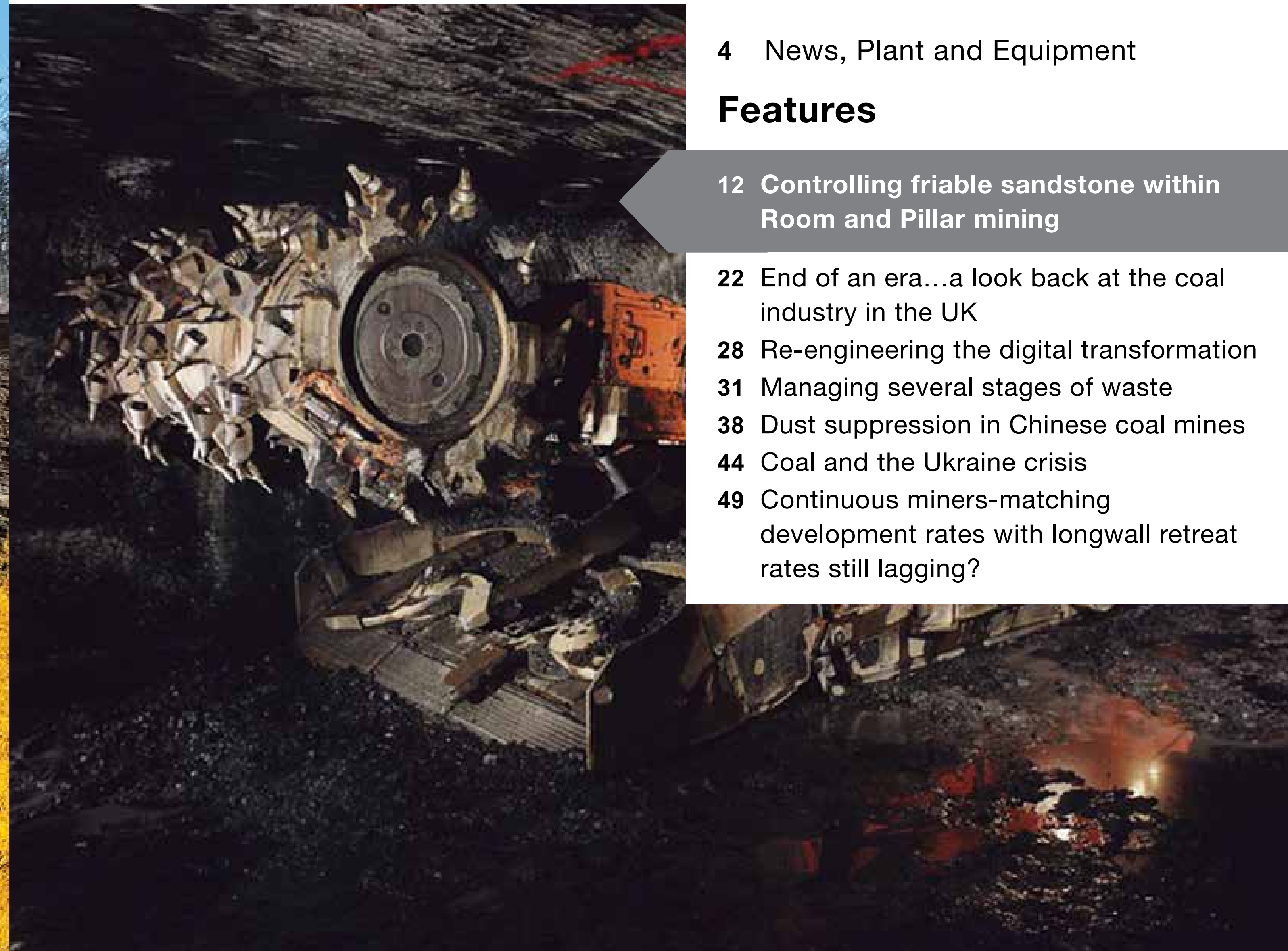
COAL INTERNATIONAL

Volume 270 · Number 3

May-June 2022

Volume 270 • Number 3 • May-June 2022

CONTENTS



Features

Martin Engineering

Decades of experience allow us to provide you with a cleaner, safer and more productive operation.

Managing Director and Publisher: Trevor Barratt

International Sales:
Gordon Barratt +44 1909 474258 gordon.barratt@tradelinkpub.com
Gunter Schneider +49 2131 511801 info@gsm-international.eu

Graphic Designer: Sarah Beale sarah@g-s-g.co.uk

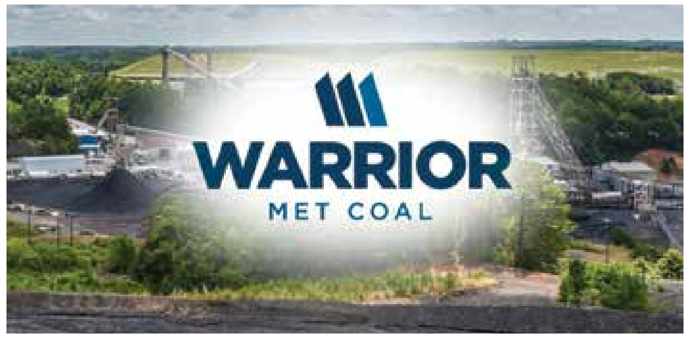
Published by: Tradelink Publications Ltd.
16 Boscombe Road, Gateford, Worksop, Nottinghamshire S81 7SB

Tel: +44 (0)1777 871007
Fax: +44 (0)1777 872271
E-mail: admin@mqworld.com
Web: www.mqworld.com

All subscriptions payable in advance.
Published 6 times per year, post free:

UK: £140.00 **Worldwide:** £160.00 | ISSN No: 1357-6941 | D-U-N-S No: 23-825-4721

Warrior to invest $700m in new US mine



Warrior Met Coal announced that it was relaunching development of its Blue Creek reserves into a new longwall mine, located in Alabama near its existing mines.

Previously, the company delayed the development of the Blue Creek reserves, owing to uncertainty over Covid-19, as well as market conditions amid a labour strike at the time.

"Blue Creek is truly a world-class asset and our commitment to this new initiative demonstrates our continued, highly focused business strategy as a premium pure-play met coal producer," said CEO Walt Scheller.

The Blue Creek development will be a single longwall mine and is expected to have the capacity to produce an average of 4.8-million short tons a year of premium high-vol A met coal over the first ten years of production.

Warrior noted it was one of the last remaining large-scale, untapped premium high vol A met coal reserves in the US.

Once fully developed, the company expects Blue Creek to increase Warrior's yearly production capacity by 60% and expand its product portfolio to its global customers, by offering three premium hard coking coals that are expected to achieve the highest premium met coal prices in the seaborne markets.

The company will invest between $650-million and $700-million over the next five years to develop Blue Creek with expected spending in 2022 of about $45-million to begin the project.

CFO Dale Boyles said that Warrior would fund the 2022 capital expenditure requirement from internally generated cash flow and cash on hand.

"We plan to be opportunistic in evaluating funding alternatives for Blue Creek, which we view as manageable given our current liquidity position and ability to utilise existing free cash flow and equipment financing."

Warrior's strong cash flow generation and current available liquidity, as well as the ability to finance $120-million to $130-million of capital expenditures through equipment leases, allows the company to be opportunistic as it evaluates funding options for Blue Creek with the goal of maintaining an efficient and low-cost capital structure.

Using an assumed met coal price of $150 a metric ton, the projected net present value is about $1-billion over the life-of-mine (LoM) with a projected after-tax internal rate of return of nearly 30% and an expected payback of two years from initial longwall production.

Based on the current schedule, Warrior expects the first development tons from continuous miner units to occur in the third quarter of 2024 with the longwall scheduled to start up in the second quarter of 2026.

Warrior controls about 70-million short tons of recoverable reserves and 49-million short tons of resources at Blue Creek, which totals more than 119-million short tons. Warrior could acquire adjacent reserves that would increase total recoverable reserves at the mine. The inclusion of all coal reserves, resources, and adjacent properties would extend the LoM reserves to about 170-million short tons.

Under this expanded mine plan, Blue Creek is expected to have a mine life of about 50 years assuming a single longwall operation.

Aussie billionaire aims to mine $8bn US fund for coal-to-hydrogen industrial conversion

Twiggy Forrest-owned Fortescue's project to tap renewable energy on Washington state grid – where surplus hydroelectric power usually exported to Canada and western seaboard – for clean hydrogen production at Centralia site

Fortescue Future Industries (FFI), owned by Australian billionaire Andrew 'Twiggy' Forrest, is planning to convert a former coal mine in US state of Washington into a green hydrogen production facility, using funds it hopes to win from the federal government's $8bn H2 hub fund, the company said recently.

After signing a binding exclusivity agreement with site developers Industrial Park at TransAlta (IPAT), FFI has now launched a feasibility study into a plan to convert the Centralia coal mine, which closed in 2006, into a 300MW green hydrogen facility.

FFI is rumoured to be targeting production of 110 tonnes of green hydrogen a day from the plant, equal to 40,000 tonnes per year. Billionaire Forrest's FFI needs 450GW of wind and solar by 2030 to meet its green hydrogen target.

The fuel is earmarked for use in heavy transport, long-haul trucking, ports, aviation, and heavy industry, and FFI plans to staff the project with employees of the nearby Centralia coal-fired power plant, which is due to close in 2025.

Significantly, the project is expected to source power from a portfolio of grid-connected green energy, Recharge understands, rather than dedicated renewable power plants.

Two thirds of grid electricity in the state is sourced from hydropower, with a further 9% sourced from non-hydro renewables, mostly wind and biomass.

Coal mines hastily restart production to manage energy crisis, leading to deadly accidents

According to investigations into these cases, in a span of five days, two coal mining accidents in Guizhou province resulted in 22 worker deaths. A roof accident at Sanhe Shunxun Coal Mine took the lives of 14 workers, and a coal and gas explosion at Limin Coal Mine resulted in eight deaths.

According to CLB's investigations into these cases, the administrative processes in place to regulate the industry and monitor workplace health and safety all failed to save these 22 workers. For example, in June 2021, the government fined the Sanhe Shunxun mine 1 million yuan and ordered it to suspend operations for one month. As for the Limin mine, although it employs 88 workers, according to its annual report, only 5 are insured. Under China's labour laws, employers are required to pay into several types of social insurance for each employee, one of which is workplace injury insurance.

The current supervision structure consists of inspectors who conduct random spot checks, since supervising each individual mine is not feasible. Before the Limin explosion, the nearby city of Guiyang only had four people responsible for these inspections. However, instead of remedying problems discovered during inspections, mines typically are able to pay fines and take other performative measures to continue production.

Management of China's energy crisis has contributed to these deadly accidents. Rising coal prices, a move toward more sustainable energy options, and an energy shortage through much of 2021 led to increased output at the Guizhou mines. In December, the daily output of coal in Guizhou increased from less than 300,000 tonnes in the previous period to more than 350,000 tonnes. Before this year's Lunar New Year, the Provincial Energy Bureau encouraged coal mining companies to limit their days off. Then, on 15 February, Guizhou announced that 100 percent of its coal mines would resume production. The deadly accidents at Sanhe Shunxun and Limin occurred just after.

In the early 2000s, China's coal mines were considered the world's most dangerous places to work. The mechanisation of mines reduced worker deaths through the 2010s, and by 2014, the number of workers killed in coal mine accidents dropped to less than 1,000 that year. In 2020, the number fell to 225.

Although the government closed small-scale mines in townships that have poor safety measures, these mines typically resume production when the economy booms and coal is in high demand.

Accident response in the industry follows a predictable cycle. After a major accident, the authorities will stop all production for a time, and then restart without any meaningful changes to prevent future occurrences. This is just what happened in Guizhou: a December 2019 accident killed 16 people, and the provincial government responded by ordering coal mines with an annual output of less than 300,000 tonnes to stop production and for other mines to be renovated. In 2020, the death toll from coal mine accidents in Guizhou dropped to six, but in 2021, it rose again to 23. With the Sanhe Shunxun and Limin mine accidents taking 22 lives already this year, the measures taken since 2019 are short-lived.

When asked about the Sanhe Shunxun coal mine, the Zhenfeng county trade union said that they were not sure whether there was a trade union at the mine. The trade union at the next higher level, the Qianxinan trade union, believed that supervising production safety was not a trade union responsibility, but rather is the sole responsibility of the emergency management bureaus. However, CLB notes the trade union has held work safety competitions and contests in the past.

As for the Limin coal mine accident, neither the Qingzhen county trade union, the emergency management bureau, the industry and information technology bureau nor the municipal government hotline knew whether migrant workers had joined a union at the mine.

CLB also called mining industry trade unions who said that it was up to local trade unions to supervise companies on the ground. The union official said industry trade unions only give instructions, including organising campaigns and doing research.

At the provincial level, the Guizhou work safety bureau said that the two mines involved were privately owned. Not all private companies need to form a union and they were unclear on whether any such union would be authorised to monitor production safety.

Although the *Work Safety Law* stipulates the trade union's role in supervising safety measures in the workplace, the union staff we called insisted that legal provisions were just principles, and that enforcement depends on local government support. These types of responses show that government departments and unions alike lack understanding of the responsibility of grassroots unions and the role of trade unions laid out in the law.

Without trade unions stepping in to ensure workers are safe, and without government departments coordinating to share information and ensure that companies have established trade unions, accidents will continue to be treated as emergencies rather than preventable occurrences. This systemic failure means that workers have no way of reporting threats to their safety, and preventable accidents will continue to happen. This outcome is not what anyone wants to see, but without involving workers and the union in workplace safety and accident prevention, it is the only result we can foresee.

NEWS, PLANT AND EQUIPMENT

India's energy crisis has power giant rushing back

India's state-run electricity giant NTPC Ltd. plans to expand its coal-fired power fleet with a first new project in six years, a policy shift that reflects alarm over the nation's worsening power crisis.

New Delhi-based NTPC will this month award a contract to construct a 1,320-megawatt plant in Odisha, according to a company official with knowledge of the plans.

The company will also consider awarding contracts for two previously stalled expansion projects at its Lara and Singrauli sites in central India, the official said, requesting anonymity as the plans are still private.

Several states across India are suffering prolonged blackouts as scorching heat waves boost energy demand at a time when coal stockpiles are dwindling and nations globally are contending with tight fuel markets. Disruptions to electricity supply are lasting as long as eight hours a day in some areas.

NTPC previously slowed plans to advance the Lara and Singrauli projects as electricity demand faltered during the pandemic. The producer has also been focusing on proposals to increase renewable energy capacity, rather than coal.

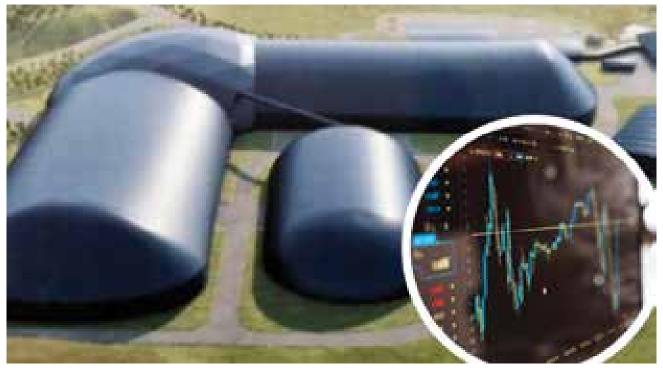
Despite a near-term addition to its coal fleet, the company will stick to a target to rapidly expand clean power capacity, the official said. NTPC is aiming to cut the share of fossil fuels in its energy mix to about half by 2032 from 83% currently.

NTPC's plans for the Odisha plant show how India, which still relies on coal for about 70% of electricity generation, can use the fossil fuel more efficiently, according to R. Srikanth, a professor of energy and climate at National Institute of Advanced Studies in Bengaluru.

"One way to do that is phase out all old power plants and replace them with modern plants that consume less coal to produce the same amount of energy," Srikanth said. "We need to stop defaming coal."

NTPC's new facility will replace a smaller plant at the same site that was phased out last year after more than five decades.

The producer is also taking steps to address the coal shortages that are prompting India energy crunch. Imports will be increased to 20 million tons during the fiscal year to March, while NTPC will aim to boost annual output at its own mines by about 86% to 26 million tons.



Market for Cumbrian coal declining fast as European steelmakers go green

Cumbria's coal mine has seen a decline in potential market according to a new analysis.

According to data published by Friends of the Earth, the proposed mine at Whitehaven in Cumbria's potential market will fall.

The declining market is a result of decisions taken by steelmakers across Europe to move away from coal and towards greener production methods.

It risks the mine becoming a stranded asset long before its proposed closure in 2049.

Levelling Up Secretary Michael Gove is due to announce on or before 7 July whether he is granting planning permission for the coal mine.

West Cumbria Mining say that up to 13% of the mine's coal would be used by the UK steel industry, but British Steel, one of the two main customers, has expressed doubts about whether it can use the coal and has said it is not lobbying for the mine to be built.

The remaining coal would be exported to steelmakers in mainland Europe. However, analysis shows that three-quarters of the coal-fired blast furnace steelmaking capacity in the EU 27 will reach the end of its operational life by 2030.

Companies have made announcements about the future of over two-thirds of this capacity, and all of these involve moving away from coal towards greener production methods.

This means that the market for coking coal in the EU will decline significantly by the end of the decade and if the current trend continues, it will decline further by the mid-2030s as more blast furnaces reach the end of their operational life.

Friends of the Earth energy campaigner, Tony Bosworth, said: "The UK steel industry will only buy a small percentage of the Cumbrian coal, and with European steelmakers already moving to greener steel production, the market for this mine is declining before it has even opened.

"Nor will the mine replace coal from Russia – even its developers don't claim that.

"The Whitehaven mine risks becoming a stranded asset with no market for its coal and potential consequences for the jobs the developers claim it will bring.

"With the world facing a climate emergency, green steel is clearly the future – something that any sensible government should embrace.

"Michael Gove must reject this mine and ensure that areas such as West Cumbria are at the heart of the green industrial revolution that the UK so clearly needs".

NEWS, PLANT AND EQUIPMENT

Against the thud of artillery, miners struggle on

Then imagine doing that in a war zone.

"It's scary, but what can you do? We don't have many other options," said Ukrainian nurse Ira Yusko, 30, smiling grimly, as she switched on her headlamp at the Toretsk coal mine in the eastern Donbas region.

Around her, more than a dozen miners – their faces already smeared with grime – shuffled forwards in the dark towards a rattling iron elevator that stood waiting to take the group 800 metres underground for a six-hour shift.

"We try to be positive. But it's hard on the soul. Depressing. These are terrible times. It's sad at home too – my wife is gone," said Vitaly Vahorder. He's spent half his life working at the Toretsk mine. His family recently joined the exodus heading west to safer locations.

Outside, the occasional boom and crunch of artillery fire echoed across the wheat fields from the front lines 4km to the east and south, where Russian troops are struggling to gain ground against fierce Ukrainian resistance in Donbas.

"People go down the mine knowing they may not come back up. And when you do come back up, anything can happen – the town is constantly being bombed," said Anatoly Sholokhov, deputy head of Toretsk's coal miners' association, as he watched the elevator door slide shut. The 69-year-old miner was born in the town and was once its mayor.

The coal mines, their steep-sided slag heaps dotting the horizon like dark pyramids, have been a defining feature of eastern Ukraine for well over a century. They provided the Russian Empire, and then the Soviet Union, with much of its raw energy. But the collapse of the USSR in 1991, the past eight years of separatist conflict with pro-Russian militias, and the Kremlin's new offensive have combined to force most of the mines to close.

One of many concerns today is that the latest mine closures are happening abruptly, and without proper safety measures, causing old shafts to flood with highly toxic water that threatens to poison local rivers.

"The danger comes when you stop several mines at once," said Anatoly. "You can't control where the ground water goes. It would be a disaster if it comes to the surface. This whole area would become uninhabitable. So, an ecological crisis looms over our town. May God prevent these mines from stopping. If the work stops and water begins to flood the mines, it could cause a catastrophe,"

Only two mines are still working here in Toretsk – formerly called Dzerzhynsk in honour of the founder of the Communist secret police.

Driving in from the west, past Ukrainian army checkpoints and roadblocks and into the near-empty town with its Soviet-era architecture and monuments, is like stepping back into the past. A Soviet red star still clings to the top of one of the oldest towers at the Toretsk mine, which first began producing coal in the 1930s, and was badly damaged during World War Two. The mine appears to have experienced few improvements, or even licks of paint, since it was refurbished in 1955.

Recently, staff showed visitors around the site. Giant pieces of rusting machinery sat beside doodle-like swirls of rail track, where a lone female worker was busy pushing mine carts into a wooden shed by hand. Two giant slag heaps behind the mine were partially covered with trees and undergrowth. A huge tree grew through one ancient winding wheel. Overhead, floorboards creaked ominously as staff walked along a footbridge from the shaft back to the communal shower block – currently without water, like the rest of the town, due to blockages on a nearby canal which locals blamed on the war.

Imagine being a coal miner, descending into a deep, ageing, rickety mineshaft.

After years of conflict, most of eastern Ukraine's mines have been forced to close.

The front lines are just four miles from the mine.

"There's no water anywhere in this town. You go to the toilet – but how do you flush? When it rains, everyone in our apartment block goes out to collect rainwater," said Vitaly.

Only a third of the mine's staff have stayed on in the town since the Russian offensive began earlier this year – some out of loyalty to the mine itself, but mostly for financial reasons.

"I've been working here for twenty years. I went straight to the mines after school. We don't have any other professions here. No factories. We earn 8,000 to 10,000 hryvnias a month (£220 – £275, $275 – $343) and with the current prices that's nothing, tiny, no better than a student's stipend," said Yuri Podlutsky.

As a group, the miners appeared reluctant to pass judgement on the war or President Putin directly. Many of them are Russian-speaking and appeared keen to avoid territory that could cause frictions within a tight-knit community. But several men acknowledged a strong nostalgia for the Soviet era and the times when Ukrainians and Russians worked side by side in the mines.

"Whether you want Putin or not, we still need to live and work. There are a lot of 'Soviets' here," said Vitaly. "I consider myself simply a local. Some of us speak Russian as our first language. But we all share the same sky."

Only a third of the mine's staff remain since the Russian offensive began.

Eastern Cape residents hope piloted mining will result in economic growth

Residents of Indwe, near Cacadu, in the Eastern Cape, hope the piloted coal mining in the area will change the lives of the impoverished communities.

43 villages, which fall under the Gumamhla Trust, want a clear beneficiation policy that is in line with the mining charter.

The government says coal mining will be a catalyst for economic growth and job creation in the area.

The coal belt contains three small rural towns, Dordrecht, Indwe and Cala. Indigenous landowners started illegal mining enterprises at Indwe decades ago. They traded with raw coal on the black market.

The residents say they want a coal mining company that recognises beneficiation and the history of coal mining in the area. They also want proper public consultation.

Tshondaxola Matiwane says, "We have to know what is taking place now, we are not happy about this programme of mining. We need DMR to come to us, we need the municipality to come forward to us, not somebody else who is coming to run this programme without consulting the local people."

Xolile Maketesi adds, "This is our land, these people came up with dams here and these dams are contaminated with chemicals. Our livestock is dying and these chemicals pose a danger to the communities around this mining. We want it to be protected from our livestock. Livestock drink from this contaminated dam."

A local businessman, Willem Strapelsberg, hopes the government will speed up the consultation process as they believe coal mining will change the face of eMalahleni.

"I think that there is still, especially with supply for electricity supply or coal whatever, I still feel there is a future in this mine. They have been saying the coal is not of good quality but still, I still believe that there is a way to get this coal mining up and running and we need the people, we need the government to try and get this, especially for our people. We have not had job creation we need this for the local people, especially for the businesses as well, this is our last hope."

According to the government, mining in the area has the potential to change the province's economic outlook.

The mayor of the Chris Hani District Municipality, Wongama Gela claims that jobs will be created.

"Mining activities are regulated and there are quite a number of regulations that some include the consultation of communities so the reopening of that mine at Emalahleni will yield a number of spin-offs in terms of the economic spin-offs. The economic activities that may accrue will also change the face of Emalhaleni, the face of the district and indeed that may work to contribute to the economic fortunes of the Eastern Cape province."

Consultation with the communities is currently taking place. Villagers want the government and the mining company to agree on how they will benefit from coal mining in the area.

NEWS, PLANT AND EQUIPMENT

US companies struggle to cash in on shortages in Europe

US coal producers are seeking to boost exports to cash in on soaring prices since Russia's invasion of Ukraine but face big headwinds including shipping bottlenecks, labour shortages and a dismal long-term outlook discouraging investment in new mines.

The outlook means the US, which holds the world's biggest reserves of coal, is unlikely to play a major role in international efforts to expand shipments of the fuel to Europe ahead of an expected EU ban on Russian imports in August to punish Moscow for the invasion.

It also means the rally in global coal prices is unlikely to pull the US coal industry out of a more than decade-long tailspin driven by federal and state efforts to slash carbon emissions that have led utilities to replace coal with cleaner-burning natural gas, and solar and wind power. President Joe Biden has set a goal to decarbonise the US power grid by 2035 to fight climate change.

"The ability of US companies to respond [to the price rally] has been limited by logistics challenges, like most industrial activity at the moment," said Ted O'Brien, managing partner and chief commercial officer at Oluma Resources, a Pittsburgh-based marketer of the fuel, citing clogged railroads, labour shortages and the unavailability of new equipment.

Ernie Thrasher, CE of Xcoal Energy & Resources, a coal marketer, estimated that bans on Russian coal could remove 114-million tonnes a year from global markets, but that the US would be poised to fill less than a tenth of that given the lack of investment in the US industry.

"That's really the issue," said Thrasher. "There's been virtually no capital invested in the industry since 2015." Europe is likely to rely most heavily on other countries such as Colombia, Indonesia, SA and Australia to replace Russian coal, he added.

US coal production year to date is up 3.8% from the same period in 2021 at about 203.7-million short tonnes, according to the latest data from the Energy Information Administration (EIA), marking a slight recovery from the depths of the Covid-19 pandemic when output hit the lowest level since 1965.

But exports have not kept up. Shipments of US coal abroad in the first quarter of 2022 slipped about 2.5% year on year to about 20.2-million tonnes, the EIA said. And the logistics hurdles prompted the EIA to lower its 2022 US coal export forecast to 85.7-million tonnes, down about 3.7% from its previous prediction in April.

The EIA said US exports are expected to rebound about 3.6% in 2023 to 88.8-million tonnes.

One company that expects its exports to do well is Alliance Resource Partners, which has mines from Illinois to West Virginia. President and CEO Joe Craft sees the Ukraine war driving US export prices for both thermal coal burned in power plants and metallurgical coal used to make steel higher than prices for domestic coal for at least 18 months.

As a result, Alliance's export volumes should be more than 6-million tonnes this year, up from about 4-million tonnes last year, and is most likely to grow by an additional 1.5-million tonnes in 2023, Craft said in a first-quarter earnings call in May.

But an industrywide expansion of exports is unlikely to happen quickly as few companies have new mines coming and most new investments are going towards sustaining output from ageing facilities, said O'Brien of Oluma.

Arch Resources does not anticipate investment in new mines for thermal coal, CEO and president Paul Lang said during the number two US coal supplier's earnings call in April.

"I think we'll continue to generate cash out of these assets, but we're simply not going to put any more cash into them," Lang said. "It's not what our shareholders want and I don't think it's a good investment for us."

The National Mining Association (NMA) industry group said the supply chain problems with rail, the primary means of transporting coal, are costing companies both in lost shipments and additional labour.

"Mining companies are facing enormous difficulties getting coal to the consumer," Katie Mills, an NMA lawyer, said late in April in testimony to the Surface Transportation Board.

NMA spokesperson Ashley Burke said the industry is "ramping up as much as possible" to supply European buyers, but faces "limits to what the rail transport and ports can handle".

West Virginia mines struggling through hiring shortage as demand increases worldwide

"They can't mine it fast enough," said Benwood Economic Development Director Frank Longwell. "That's how we pay our bills here in the community."

Longwell remembers when coal mines were so popular, they were turning away job applicants. You can make $100,000 a year mining coal in Benwood. But coal miners are going through a hiring shortage, which is hurting production. "The main complaint that I hear on a daily basis: 'We need people,'" Longwell said. "Some of the production does get cut back because they don't have the people."

Coal mining is a demanding job. Benwood is losing coal miners because of that.

"It's just too much," Longwell said. "Twelve hours, six days a week. That kind of thing."

And they might not be coming back.

"Getting enough sufficient levels of labor into those mines to be able to increase production, they just can't really do it that much," said West Virginia University business and economic research expert Brian Lego.

The shortage of coal miners is hurting coal production in Benwood.

As a result, companies have had to cut back. Global demand for coal increased by 6% last year and could rise even more this year.

"We're seeing prices climbing rather aggressively over the past several months," Lego said. "Due in large part to Ukraine, but also to the global growth in general."

Controlling friable sandstone within Room and Pillar mining

The ability to efficiently control sandstone pillar spalling is extremely important in ensuring the safety and high-efficiency production of sandstone mines. The increase in size is usually suggested as a remedy for pillar spalling, but none of the suggested remedies reflect the influences of geotechnical properties of rock mass on stability control. Some sandstone mining practices have proven that increasing the size of pillars cannot effectively control pillar spalling. The relationship between the strength of St. Peter sandstone pillar and pillar loads was theoretically analyzed in the current study, in order to examine the influences of geotechnical parameters of sandstone on the stability of pillars and control pillar spalling. The key geotechnical parameters that influence the stability of sandstone pillars were also examined. Subsequently, the pillar instability mechanism and influences of geotechnical parameters on pillar stability were investigated by Finite Difference Method. Finally, a ground control method using shotcrete on pillar was proposed for increasing the stability of pillars. Results demonstrate that compressive stress on the St. Peter sandstone pillar is considerably larger than the compressive strength after mining, resulting in the evident deformation of most regions. The relation curves of displacement at the pillar top with internal friction angle and cohesion are in the power functional distributions, but the change of cohesion is more significant in the pillar strength. The displacement at the pillar top gradually decreases with the increase in internal friction angle, whereas the plastic failure regions of pillars gradually decrease from the bottom to the upper parts with the increase in cohesion. A field industrial test proves that shotcrete on pillars can increase pillar strength, which effectively controls the pillar spalling. Research results provide theoretical and practical guidelines to enhance the stability of pillars under the same geotechnical circumstances.

ROOM AND PILLAR

INTRODUCTION

As an underground mining technique that is environment friendly, room and pillar mining has been widely used in America and Australia. The core of the room and pillar mining system is to mine rooms according to the design and leave pillars to support and control the roof and surface subsidence[1-2]. Pillar stability is the key element of safe room and pillar mining. Pillar spalling is one of the typical instability forms of sandstone; therefore, controlling pillar spalling is crucial in ensuring the safe and high-efficiency production of sandstone mines[3].

In ground control, room and pillar mining is believed to alter the in situ state of stress in strata, and stress overlying strata can be transferred to the adjacent pillars after room and pillar mining. Consequently, room and pillar mining results in increasing stress on the pillars. Meanwhile, the horizontal deformation of pillars induced by the external effect is free of constraints due to the presence of rock masses on both sides after room mining, thus decreasing pillar strength accordingly. Hence, the rock mass of pillars develops deformation failures. Pillar instability control depends on the retention of the reasonable size and shape of pillars so that they can endure mining-induced stresses[4-6]. Size effect theory of rock mass indicates that rock mass failure is mainly caused by the development of the structural surface in rock mass and the failure of the weakest structural surface. When the pillar size is increased to a certain critical value, the rock strength remains constant with the increase in pillar size. The pillar strength is equal to rock mass strength under this critical size. Based on several engineering practices, pillar stability control is accomplished by designing reasonable pillar size according to the critical pillar strength. Although this theory is simple, the influences of the geotechnical parameters of rock mass on pillar instability are neglected for the pillar strength analysis, thus failing to achieve a good ground control result for some rock mining practices.

Compared with size effect theory, two-region constraint theory involves the influences of the internal friction angle of coals. According to this theory, a central elastic zone and two-side yield zones are formed in pillars after mining. The central elastic zone is compressed in three directions due to constraints from the two-side yield zones. Two-region constraint theory estimates pillar strength based on the three- directional strength characteristics. Although this method has been used extensively, the influences of cohesion on pillar strength are neglected.

Owing to disturbances caused by room and pillar mining, the different degrees of stress concentration develop between St. Peter sandstone pillars and cap rocks in Pattison Mine, which further cause many large-scaled instability behaviors, including pillar spalling and collapse. Changing pillar size during mining fails to control the pillar -spalling behavior effectively. St. Peter sandstone has extremely high internal friction angle (in the range of 57°-69°) and is virtually cohesionless [7-9]. The high internal friction angle makes sandstone pillars bear extremely high loads under small deformation, whereas the low cohesion leads to extremely weak sandstone pillars after mining disturbances. Therefore, internal friction angle and cohesion can both considerably influence the mechanism of St. Peter sandstone pillar instability. Thus, the pillar stability control cannot be accomplished without consideration to internal frictional angle and cohesion.

In the current study, the influences of the geotechnical properties of St. Peter sandstone in Pattison Mine on the deformation failure of pillars were studied using theoretical analysis and finite difference numerical simulation. The pillar spalling mechanism was disclosed, and special ground control measures were proposed.

2. STATE OF THE ART

Traditional theories of pillar stability state that controlling pillar stability in room and pillar mining is performed by increasing the strength of pillars and their ability to bear mining-induced loads. Studies on pillar strength characteristics based on laboratory tests, theoretical analyses, and numerical simulations have been reported, and some calculation methods of pillar size applicable to engineering design have been developed to control pillar spalling. However, these studies mainly focus on the influences of rock mass size on failure mode, ultimate bearing capacity, and load-deformation process of pillars. For example, Renani *et al.*[10] studied the progressive failure of hard rock pillars using two- and three-dimensional finite difference analysis. The stress-strain curves indicated that pillars exhibited strain-softening behavior when the width/height ratio of pillars was lower than 2 and strain-hardening behavior when the width/height ratio was higher than 2. Moreover, a constitutive model on progressive damages of rock mass in pillars, which considered cohesion weakening and friction strengthening in rock mass, was proposed in numerical calculation. Poulsen *et al.*[11-12] introduced a stress calculation method that considered the shape and spatial position of pillars. In addition, 120 groups of numerical models were constructed through finite difference analysis to study pillar stability under filling effect of roadways. They found that pillar strength was directly related with filling degree and that viscous filling body increased the pillar strength.

Meanwhile, the influences of filling parameters on pillar strength have been discussed through numerical calculation by adjusting cohesion in the constitutive model, whereas those of coal parameters were neglected. Yang *et al.*[13] proposed a formula of full-scale mine pillar strength based on laboratory scale strength obtained from specimens. The pillar size calculated by this formula ensured pillar stability when the width/height ratio of pillars ranged within 0.6-0.8 and the safety coefficient was higher than 1.5. Moreover, rock mass, pillar conditions, mining size, and complete rock strength were considered during calculation. Guy *et al.*[14] indicated that the stability of the pillar system was related to the post-failure stiffness of the pillar and its interaction with overburden stiffness. They also found that the post-failure stiffness of pillars was a function of pillar width/height ratio. In addition, they examined the influences of pillar size and shape on pillar system during the stability evaluation of the system, except for the relationship between loads of overlying strata and pillar strength. Jaiswal *et al.*[15] considered coal as a Hoek-

Brown strain-softening material and proposed a formula to estimate pillar strength during mining of India Mine based on Finite Element Method. In this formula, the extension deformation of pillars is the function of confining pressure and plastic shear strain. The numerical calculation model was also calibrated by using data from actual mining situations of India Mine. Kaiser *et al*.[16] found that the pillar strength in the core region estimated by the Mohr-Coulomb or Hoek-Brown criteria was lower than the actual pillar strength, and that the pillar size designed according to existing empirical formula for controlling pillar stability was poor. Moreover, the S-shaped criteria of the rock mass failure of pillars were proposed to construct the constitutive relationship for numerical calculation, which could increase the evaluation accuracy of pillar strength. Based on a case study of rock mining in America, Dolinar *et al*.[17-18] proposed an estimation formula of pillar strength and provided suggestions for good pillar designs. Although this formula and relevant suggestions considered the potential influences of rock discontinuity on pillar strength, they were based on experiences of rock room mining in America and could only be directly applied to pillar design under similar conditions. Meanwhile, Walton *et al*.[19] constructed a constitutive model to describe strength and dilatancy deformation of brittle rocks based on laboratory test data. Simultaneously, the surrounding stress and deformation distributions of the shaft were predicted through numerical calculation. Song *et al*.[20-21] analyzed the sensitivity of influencing factors of pillar stability based on an orthogonal test. The major influencing factors of pillar instability were also evaluated from pillar loads, pillar strength, pillar instability form, and determination of influencing factors. Nevertheless, the influences of geotechnical parameters on pillar strength were ignored. Jiang *et al*.[22] conducted a uniaxial compressive numerical simulation test of pillars using FLAC3D and analyzed the stress-strain curve characteristics of the pillar system at the instability failure. Through the calibration of coal samples, the simulation of brittle failure was controlled by changing cohesion, internal friction angle, and expansion angle, with considerations to influence the geotechnical parameters on the constitutive relationship. Through field measurement and theoretical analysis, Fu *et al*.[23] studied the occurrence mechanism and prevention measures of dynamic load pressure by analyzing critical elastic core width for small pillars to maintain stability under lead abutment pressure, overlying structure, and support loads on the working surface under dynamic loads. Although the rotation effects of overlying strata on pillars were considered, influences of pillar strength were neglected. The aforementioned studies have discussed the influences of pillar size, shape, and constitutive relations on pillar strength and analyzed failure mode, bearing capacity, and instability factors of pillars. However, none of these studies have discussed the influence mechanism of the mechanical performances of rock mass materials on pillar spalling.

To further frontier knowledge of pillar stability analysis, the correlation between pillar strength and pillar loads was analysed theoretically, and the key geotechnical parameters of St. Peter sandstone pillar stability were determined in the present study. Therefore, the influences of key geotechnical parameters on pillar stability were analyzed utilizing finite difference analysis, thus allowing us to explain the pillar instability mechanism from the perspective of geotechnical parameters and propose relevant countermeasures. The results were verified by numerical simulation and field test. This study provides theoretical and practical bases for stability control of similar sandstone pillars.

The remainder of this study is organised as follows. Section 3 introduces the project, numerical modeling, and key geotechnical parameters of pillar stability control. Section 4 analyzes pillar strength under the influences of key geotechnical parameters and discusses the influences of cohesion, internal friction angle, plastic region, and vertical stress distribution of pillars. The program for the improvement of pillar stability control is formulated, and control effect is verified. Section 5 presents the conclusions.

3. METHODOLOGY

Theoretical analysis of pillar stability

Understanding the relationship between pillar strength and pillar loads is the key to investigating pillar failure during room and pillar mining[24]. Pillar instability occurs if the pillar strength is smaller than pillar loads; otherwise, the pillar will remain stable. Therefore, the relationship between pillar strength and pillar loads was theoretically analysed to determine the influencing factors of stability of St. Peter sandstone pillars.

Pillar loads

Pillar load is usually calculated by the tributary area method in room and pillar mining. This method assumes that during horizontal mining with adequate mining areas, pillars with the same shape have equal strength and bear the same loads[25-26]. The loads on rectangle pillars could be calculated by using **Equation 1**.

Equation 1

$$P = \gamma h(W + b)(l + b)$$

Where P is the pillar load (MPa), γ is the unit weight of overlying strata (MN/m^3), h is the mining depth (m), W is pillar width (m), l is the pillar length (m), and b is the room width (m).

Pillar strength

In the mechanics of materials, loads on beams are calculated by the integration of the area below the stress curve. Pillars must be in the elastic core region for room and pillar mining in order to maintain pillar stability. The stress in the core region is hypothesized to reach the peak stress. The stress distribution curve on a pillar is given in **Figure 1**.

The bearing capacity (L) of the pillar is expressed as

Equation 2

$$L = 4 \times W \int_0^{\hat{y}} \sigma_v \, dy + (W - 2\hat{y})^2 \times \hat{\sigma}_v$$

Where y is the distance to the pillar edge (m), $\hat{y}$ is the width of plastic region (m), σ_V is the vertical stress at the place y away from the pillar edge (MPa), and is the maximum vertical stress (MPa).

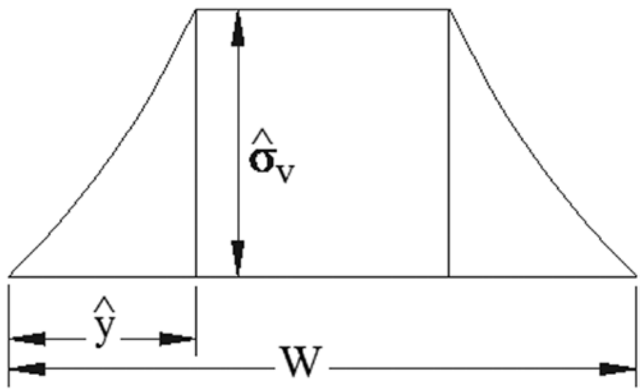


Figure 1: Stress distribution in pillar.

By integration of **Equation 2**, it is simplified into

Equation 3

$$L = \frac{2WM\sigma_0}{\tan\varphi \tan\beta}\left(e^T - 1\right) + (W - 2\hat{y})^2\left(\sigma_0 + \gamma h \tan\beta\right)$$

Equation 4

$$T = \frac{2\tan\varphi \tan\beta}{M}\hat{y}$$

where M is the height of the pillar (m), σ_O is the uniaxial compressive strength (MPa), is the coefficient of horizontal pressure, and is the internal friction angle of the pillar.

Safety factor of the pillar

The safety factor (SF) should be satisfied to maintain the stability of sandstone pillars using **Equation 5** below.

Equation 5

$$SF = \frac{L}{P} \geq 1$$

Equation 4 shows that the SF of the pillar is influenced by stress state, geometric parameters, cohesion, and internal friction angle of the pillar. However, stress state and geometric parameters of the pillar are determined by field production technological conditions. Given that St. Peter sandstone has special mechanical properties, the influences of these mechanical properties on the stability of sandstone pillars are also remarkable. Therefore, studying the influencing mechanism of cohesion and internal friction angle on the stability of sandstone pillars provides important theoretical references to the control of pillar stability.

Finite difference numerical simulation

Introduction to the project

In this study, a numerical simulation analysis based on the actual mining of Pattison Mine was conducted. A total of 20 m × 20 m pillars remained in the Pattison Mine. Room width, mining depth, and mining height were 10 m, 44 m, and 9m, respectively. During the mining process, different degrees of surface spalling were observed on the pillar surface between the upper part of St. Peter sandstone pillars and cap rocks as a response to the mining, which further evolved into a small- scaled pillar scaling. The failure mode of St. Peter sandstone pillars was manifested by inward stratified spalling by stress concentration. Different from the overall slippage of common pillars caused by plastic failure, the failure mode of St. Peter sandstone pillars was similar to the plate or stratified failure of stratified rock mass under comprehensive effects.

Finite difference numerical simulation modeling

A FLAC3D numerical simulation model (**Figure 2**) was constructed based on the actual geometric and geotechnical parameters of St. Peter sandstone rooms in Pattison Mine. Stress, displacement, and the plastic failure of pillars were analyzed based on this model. Height and width of the constructed FLAC3D model were 13.11 m and 30 m, respectively. The room and pillar widths were 10 m and 20 m, respectively.

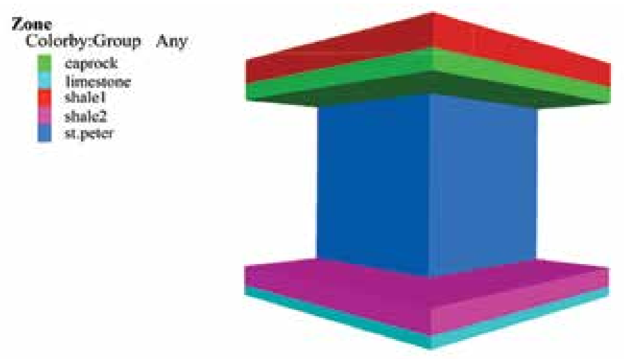


Figure 2: Numerical simulation model.

FLAC3D 5.00 © 2012 Itasca Consulting Group, Lnc.

Horizontal displacement constraints were applied at two sides of the calculation model, whereas a vertical displacement constraint was applied at the bottom. A 1.1 MPa vertical load of overlying strata was applied at the top of the model. The in situ stress was applied according to the empirical formula of 2.5 MPa/100 m. Rectangle grids were also used. The grid size on the pillar was 0.25 m x 0.25 m x 0.25 m, and the grid size at roof and floor was 0.5 m x 0.5 x 0.6 m. The Mohr-Coulomb criterion was chosen as the constitutive model. A quarter of the pillar was also chosen in the calculation, and strata with similar lithology or thin strata were combined. The model was simplified into four rock layers, including St. Peter Sandstone (pillar), shale (roof and floor), cap rocks (roof), and limestone (floor). The mechanical parameters of different rock layers are listed in **Table 1**.

Contours of stress, plastic region, and displacement distribution of pillars were obtained by numerical simulation (**Figure 3**). As shown in **Figure 3(a)**, tensile stress regions are found at the roof and floor of pillars, whereas the pillar is completely observed in the compressive stress regions. Moreover, an evident small-scaled stress concentration is observed at the corner of the pillar-cap rock interface. However, stress concentration also occurs in other regions on the interface, and the maximum vertical stress reaches

Table. 1. Mechanical parameters

Lithology	Density /g/m3	Bulk modulus / GPa	Shear modulus / GPa	Internal friction angle /°	Cohesion / MPa	Tensile strength /MPa
Shale	2350	8.8	4.3	25	2.0	1.39
Cap rock	2200	20	7.0	35	4.0	2.39
St. Peter	1900	1.4	0.8	60	0.6	0.87
Limestone	2600	22.6	11.1	30	6.0	4.39

approximately 20 MPa, which is considerably higher than the compressive strength of St. Peter sandstone. The distribution of plastic regions in **Figure 3(b)** demonstrates the evident formation of compression-shearing failure downward from the sandstone-cap rock interface because sandstone pillar is basically influenced by the compressive stress, which is considerably higher than compressive strength of sandstone. Furthermore, the plastic region presents an evident "X-shaped" distribution pattern.

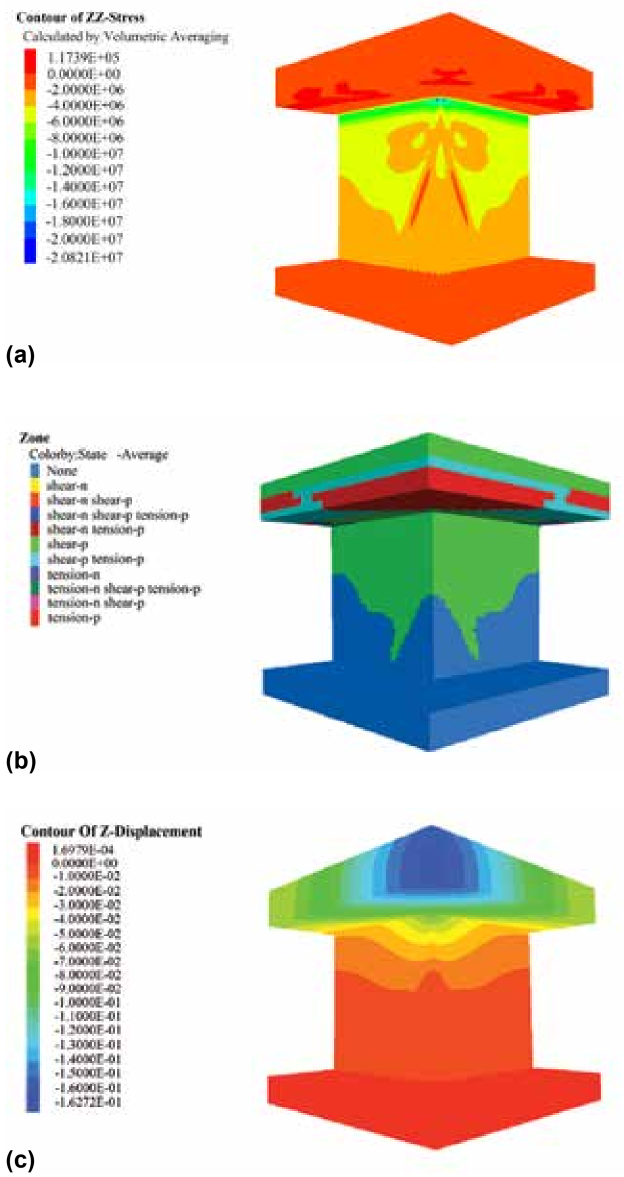


Figure 3: Contour of pillars. (a) Vertical stress contour. (b) Plastic region contour. (c) Vertical displacement contour.

FLAC3D 5.00 © 2012 Itasca Consulting Group, Lnc.

According to the contour of vertical displacement distribution in **Figure 3(c)**, regions with shearing failure on the pillar are substantially deformed, and the displacement distribution is in an evident "concave" pattern. The deformation in the pillar-cap rock interface is the highest, reaching 30 mm.

Based on the preceding analysis, the St. Peter sandstone pillar is generally in the compressive stress region after mining, and the compressive stress is considerably higher than compressive strength of the pillar, thus resulting in evident large-scaled deformation and compression-shearing failures of the pillar. An "X-shaped" plastic region is also formed.

4. TEST RESULTS AND ANALYSIS

The theoretical analysis of pillar stability reveals that cohesion and internal friction angle are two important influencing factors of stability of the St. Peter Sandstone pillar. The variation of stress state, plastic region distribution, and displacement distribution of the St. Peter sandstone pillar with cohesion and internal friction angle were analyzed by the FLAC3D finite difference numerical simulation. The numerical simulation model only changed the cohesion and internal friction angle but had consistent rock and simulation parameters with those in common models.

Effects of internal frictional angle on pillar stability

With the internal frictional angles of St. Peter sandstone ranging between 57°-63°, stress, plastic region, and displacement distributions of St. Peter sandstone under different internal frictional angles (40°, 50°, 60°, and 70°) were simulated.

The distributions of the plastic region and stress on St. Peter sandstone pillar under different internal frictional angles (40°, 50°, 60°, and 70°) are shown in **Figure 4**. From the stress contours, the pillar is observed to be generally compressed under different internal frictional angles, accompanied by stress concentration in the pillar-cap rock interface. As can be seen, stress concentration intensifies with the increase in internal frictional angle. In the distribution contours of plastic regions, the St. Peter sandstone pillar develops evident plastic failure under different internal frictional angles, which is dominated by compression-shearing failure. Almost all pillars develop plastic failures at 40°. With the increase in internal frictional angle, the plastic failure scope of pillars gradually narrowed from bottom to up. A small-scale plastic region is formed at the corner of pillar-cap rock interface when the internal frictional angle is increased to 70°.

The relation curves between displacement at the measuring points at the pillar top and the internal friction angle were

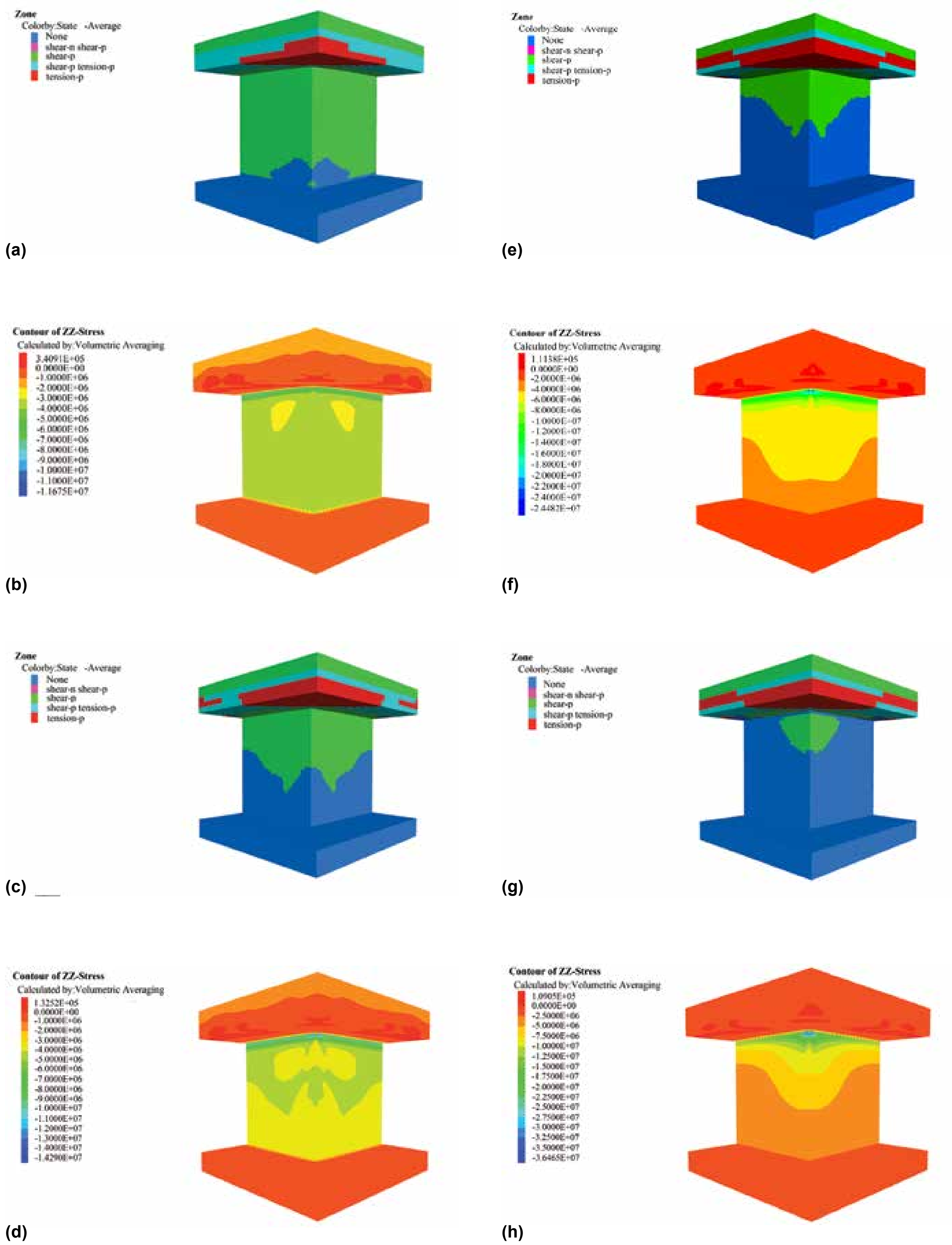


Figure 4: Plastic region and stress distribution on pillars under different internal friction angles. (a) Plastic region ($\phi = 40°$). (b) Vertical stress ($\varphi = 40°$). (c) Plastic region ($\phi = 50°$). (d) Vertical stress ($\varphi = 50°$). (e) Plastic region ($\phi = 60°$). (f) Vertical stress ($\phi = 60°$). (g) Plastic region ($\phi = 70°$). (h) Vertical stress ($\phi = 70°$).

FLAC3D 5.00 © 2012 Itasca Consulting Group, Lnc.

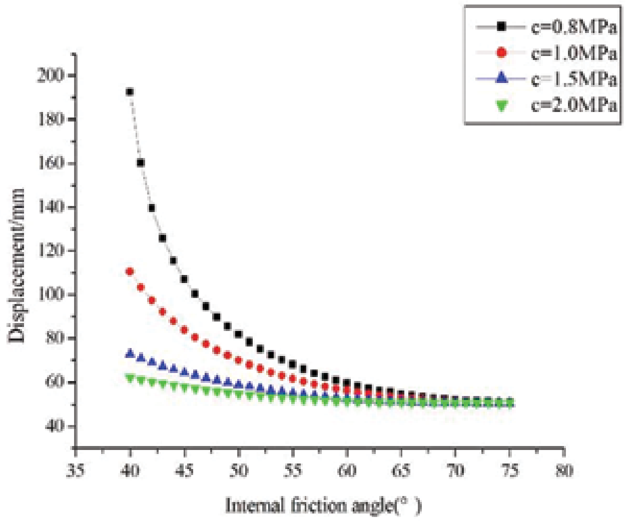
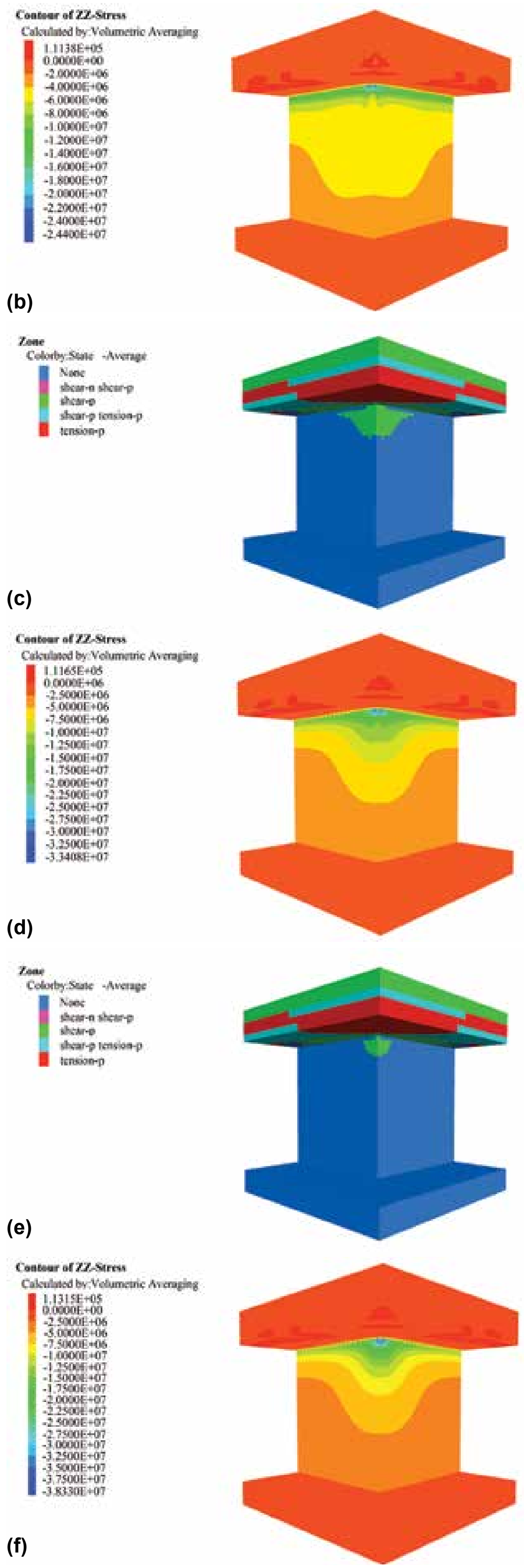


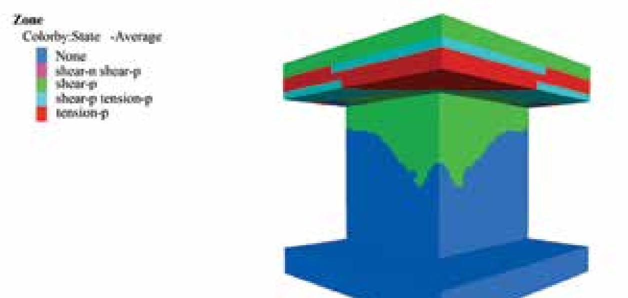
Figure 5: Relation curves between internal friction angle and displacement at the top of pillar.

drawn according to the numerical simulation results of pillar displacement distribution, in order to further analyze the influences of internal friction angle on pillar stability (**Figure 5**). These relation curves are approximately a power functional distribution. Displacement at the pillar top is gradually decreased with the increase in internal friction angle. The displacement reduction is outstanding when the internal friction angle increases from 40° to 60°, but the reduction amplitude gradually declines after 60°. This finding indicates that the internal frictional angle affects deformation of sandstone pillars mostly in the range of 40°-60°.

Effects of cohesion on pillar stability

Given that the cohesion of the St. Peter sandstone is small, influencing laws of cohesion on sandstone pillar stability were investigated by gradually increasing cohesion. Stress, plastic region, and displacement changes of sandstone pillars under different cohesion values (0.8, 1.2, 1.6, 2.0, and 2.4 MPa) were simulated by FLAC3D.





(a)

Figure 6: Plastic region and stress distribution on pillars under different cohesion. (a) Plastic region (*c* = 0.8*MPa*). (b) Vertical stress (*c* = 0.8*MPa*). (c) Plastic region (*c* = 1.6*MPa*). (d) Vertical stress (*c* = 1.6*MPa*). (e) Plastic region (*c* = 2.4*MPa*). (f) Vertical stress (*c* = 2.4*MPa*).

The respective distributions of plastic regions and stress on pillars when cohesion values are 0.8, 1.6, and 2.4 MPa are shown in **Figure 6**. The stress contours under different cohesion show that pillars are generally compressed under different cohesion, and evident stress concentration also occurs in the pillar-cap rock interface, which is similar to that caused by changes of internal friction angle. Hence, the stress concentration degree is increased as the cohesion continuously increases. However, the stress concentration degree caused by the increase in cohesion is considerably higher than that caused by the increase in internal friction angle.

The distribution of plastic regions under different cohesion values is shown in **Figure 6**. As can be seen, all pillars develop evident plastic failures under different cohesion values, which are dominated by compression-shear failures. However, the plastic failure range of sandstone pillars is considerably smaller than that caused by internal friction angle. The upper part of pillars develops plastic failure when the cohesion is 0.8 MPa. The plastic failure range of pillar is narrowed from the bottom to top as cohesion gradually increases. When the cohesion is increased to 2.4 MPa, only a small-scaled plastic region is formed at the corner of the pillar-cap rock interface.

The relation curves between displacement at measuring points at the pillar top and cohesion were drawn according to numerical simulation results of the pillar displacement distribution, in order to analyze the influences of cohesion on pillar stability (**Figure 7**). These curves are approximately a power -functional distribution. The displacement at the pillar top is negatively correlated with cohesion. Such a displacement is remarkably decreased when cohesion increases from 0 to 1.4 MPa, but the reduction amplitude declines after 1.4 MPa. This finding indicates that cohesion influences the deformation of sandstone pillar mostly when it increases from 0.

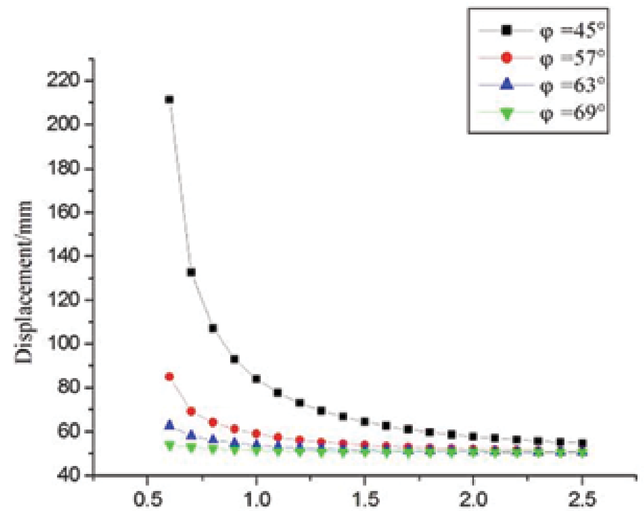


Figure 7: Relation curves between cohesion and displacement at pillar top.

Pillar scaling control

Control measures

Based on the preceding analyses, the distribution range of the plastic region and that of pillars both considerably decrease with the increase in internal friction angle and cohesion, thus improving pillar stability. Therefore, the stability of St. Peter sandstone pillars can be increased by aggregating the cohesion and internal frictional angle.

Although aggregating the internal friction angle and cohesion can realize the goal of increasing pillar stability, the internal friction angle of St. Peter sandstone is high and aggregating the internal friction angle cannot considerably improve pillar stability. Nevertheless, the cohesion of the St. Peter sandstone is low (almost 0). Increasing cohesion alone can remarkably improve pillar stability. Finally, the cohesion of the surface sandstone of pillars can be increased by shotcrete, thus enabling the increase in pillar stability.

Control program

According to the proposed control measures of sandstone stability, the shotcrete parameters are defined as follows:

(1) Given that St. Peter sandstone has high internal friction angle and low cohesion, a concrete layer was sprayed to the failure region of pillars as a form of support. The concrete strength was 20 MPa, and the concrete thickness was 10 mm. The shotcrete was accomplished twice, and the concrete mixing ratio was cement: sand: gravel: accelerator = 1:2:2:0.03 (weight ratio).

(2) Spraying shotcrete shall be performed from top to bottom and from the pillar scaling region to other regions. At concrete spraying, the nozzle is perpendicular to the sprayed surface, and the distance is controlled within 0.6-1.2 m. The concrete surface shall be kept smooth and bright with no dry spots and slippage after spraying.

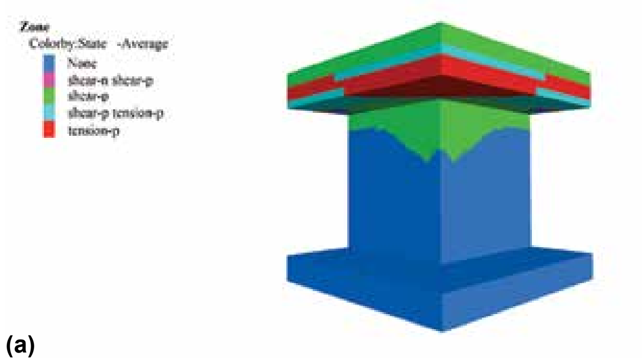
Numerical simulation of the spraying effect

A FLAC3D numerical simulation analysis of the distributions of plastic regions and the displacement on sprayed sandstone pillars was conducted based on the proposed spraying program. The results are shown in **Figure 8**. The plastic region is clearly remarkably narrowed after spraying shotcrete, accompanied by evident plastic failures of surrounding rocks at pillar corners. However, no evident large-scaled plastic region is formed in other regions. Simultaneously, the maximum displacement of pillars decreases from 211 mm before spraying to 92 mm.

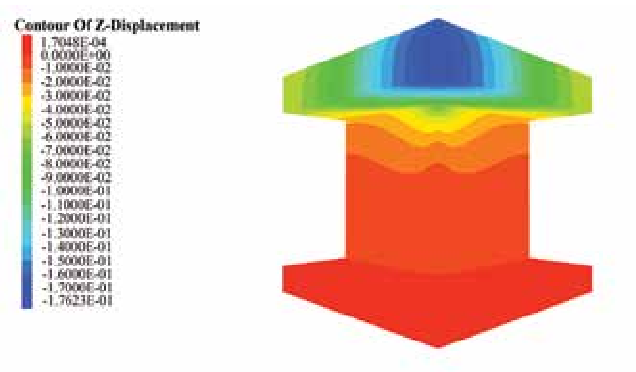
Therefore, spraying shotcrete on the surface of sandstone pillars is a reasonable and feasible scheme to increase pillar stability.

Field test

A field industrial experiment of sandstone stability control scheme based on shotcrete in Pattison Mine was conducted. The local pillar spalling was effectively controlled after grouting reinforcement, thereby meeting the requirements on safety production of mines. The spraying effect of sandstone pillars in Pattison Mine is shown in **Figure 9**.



(a)



(b)

Figure 8: Distributions of plastic region and displacement on pillars after spraying. (a) Plastic region. (b) Vertical stress.

5. CONCLUSIONS

In this study, cohesion and internal frictional angle are determined the key geotechnical parameters of pillar

stability based on theoretical analysis, in order to discuss the influences of the mechanical parameters of rock mass and disclose the internal mechanism of pillar spalling. Next, the stress and deformation distributions of the surrounding rocks on pillars under different cohesion and internal friction angles are analyzed by finite difference analysis. The pillar stability control program by increasing cohesion through shotcrete is formulated. Some conclusions could be drawn, as indicated below.

(1) Stress concentration region is developed and the overburden is increased when the sandstone pillars bear mining-induced stress. Moreover, rock mass on pillars is changed from three-directional into two-directional stress state during room and pillar mining, thereby decreasing the pillar strength and causing shear failures in most regions. An “X-shaped” plastic region is formed on the pillar body.

(2) The cohesion and internal friction angle of sandstone are key factors that influence pillar strength. The horizontal displacement of pillars presents the power functional relations with cohesion and the internal friction angle of rock mass. The plastic failure region of pillars continuously narrows with the independent or simultaneous increase in cohesion and internal friction angle.

(3) The plastic deformation of pillars decreases when the internal friction angle of sandstone increases from 0° to 60°. However, the deformation control of pillars achieves poor performances after 60°. The plastic deformation of pillars is negatively correlated with cohesion before 1.4 MPa. However, the pillar deformation remains the same with the increase in cohesion after 1.4 MPa. Thus, cohesion affects deformation of sandstone pillars mostly when it gradually increases from 0.

(4) Owing to the high internal friction angle and low cohesion of sandstone, pillar spalling can be effectively controlled by increasing cohesion and confining pressure through shotcrete and increasing pillar strength through improvement of the three-directional stress state of rock mass.

The proposed pillar stability control method by changing the mechanical parameters of rock mass is characterized by the following advantages: simple operation, low cost, and good control over pillar failure. This method lays a foundation to solve other rock strata control problems during room and pillar mining. However, this study did not conduct a quantitative analysis of the influences of spraying support assisted by anchor rod and metal mesh on the mechanical performance of pillars. Further associated studies are thus needed.

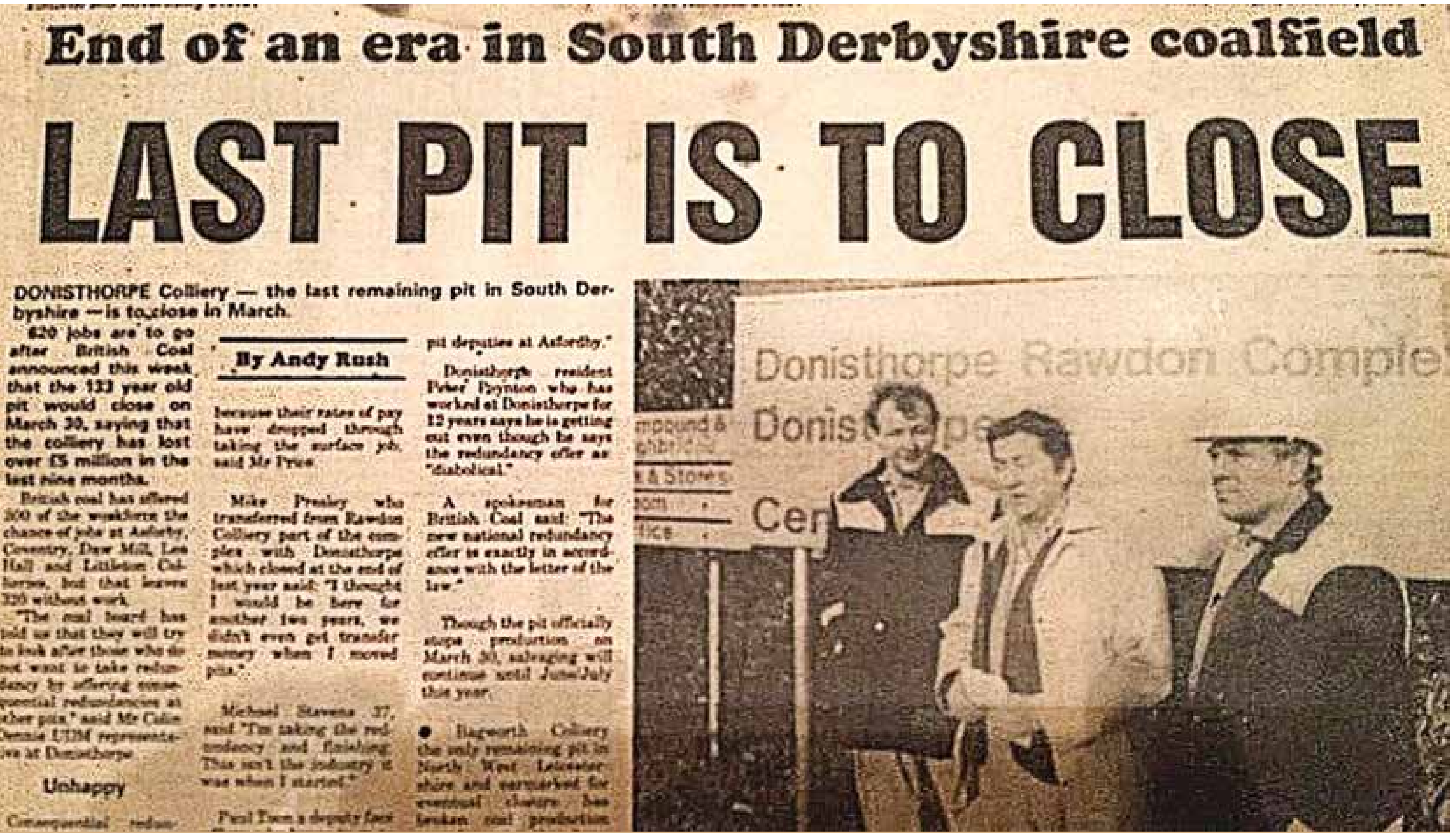
Figure 9: Industrial experiment.

ACKNOWLEDGEMENTS

The study was supported by National Natural Science Foundation of China (Grant Nos.51504183;51874232; 51804243) and Natural Science Foundation and Scientific Project Foundation of Shaanxi Province (Grant No.2015JQ5132; 17JK0486; 2018TD-038), Open Fund of Anhui Province Key Laboratory of Mining Response, Disaster Prevention and Control in Deep Coal Mine (Grant No. KLDCMERDPC13102).

REFERENCES

1. Hudeček, V., Šancer, J., Zubíček V., Golasowski, J., “Experience in the adoption of Room & pillar mining method in the company OKD a.s., Czech Republic”. Acta Montanistica Slovaca, 22(3), 2017, pp.303-312.
2. Zhang, J. X., Huang, P., Zhang, Q., Li, M., Chen, Z. W., “Stability and control of room mining coal pillars-taking room mining coal pillars of solid backfill recovery as an example”. Journal of Central South University, 24 (5), 2017, pp.1121-1132.
3. Luo, Y., “Room-and-pillar panel design method to avoid surface subsidence”. Mining Engineering, 67(7), 2015, pp.105-110.
4. Bieniawski, Z.T., “In situ strength and deformation characteristics of coal”. Engineering Geology, 2(5), 1968, pp.325-340.
5. Wilson, A. H., “A hypothesis concerning pillar stability”. Mining Engineering, 131(141), 1972, pp.409- 417.
6. Hustrulid, W.A., “A review of coal pillar strength formulas”, Rock Mechanics, 8(2), 1976, pp.115-145.
7. Payne, C. M., “Engineering aspects of the St. Peter sandstone in the Minneapolis-St. Paul area of Minnesota”. Master thesis of University of Arizona, USA, 1967, pp.5-15.
8. Dusseault, M. B., Morgenstern, N. R., “Locked sands”. Quarterly Journal of Engineering Geology and Hydrogeology, 12(2), 1979, pp.117-131.
9. Dittes, M., Labuz, J. F., “Field and laboratory testing of St. Peter sandstone”. Journal of Geotechnical and Geoenvironmental Engineering, 128(5), 2002, pp.372-380.
10. Ranani, R. H., Martin, C. D., “Modeling the progressive failure of hard rock pillars”. Tunnelling and Underground Space Technology, 74(2), 2018, pp.71-81.
11. Poulsen, B. A., “Coal pillar load calculation by pressure arch theory and near field extraction ratio”. International Journal of Rock Mechanics and Mining Sciences, 47(7), 2010, pp.1158-1165.
12. Wang, H., Poulsen, B.A., Shen, B., Zhue, S., Jiang, Y., “The influence of roadway backfill on the coal pillar strength by numerical investigation”. International Journal of Rock Mechanics and Mining Sciences, 48(3), 2011, pp.443-450.
13. Yang, H. S., Kim, W. B., Ali, M.M., “Performance of pillar design in underground stone mines that include discontinuities”. Geosystem Engineering, 15(3), 2012, pp.187-194.
14. Guy, R., Kent, M., Rusell, F., “An assessment of coal pillar system stability criteria based on a mechanistic evaluation of the interaction between coal pillars and the overburden”. International Journal of Mining Science and Technology, 27(1), 2017, pp.9-15.
15. Jaiswal, A., Shrivastva, B. K., “Numerical simulation of coal pillar strength”. International Journal of Rock Mechanics and Mining Science, 46(4), 2009, pp.779-788.
16. Kaiser, P.K., Kim, B., Bewick, R.P., Valley, B., “Rock mass strength at depth and implications for pillar design”. Mining Technology, 120(3), 2011, pp.170-179.
17. Dolinar, D.R., Esterhuizen, G.S., “Evaluation of the effect of length on the strength of slender pillars in limestone mines using numerical modeling”. In: Proceedings of the 26th International Conference on Ground Control in Mining, Morgantown, USA: ICGCM, 2007, pp.304-313.
18. Esterhuizenn, G. S., Dolina, D. R., Ellenberger, J. L., “Pillar strength in underground stone mines in the United States”. International Journal of Rock Mechanics and Mining Science, 48(1), 2011, pp.42-50.
19. Walton, G., Diederichs, M.S., “A mine shaft case study on the accurate prediction of yield and displacements in stressed ground using lab-derived material properties”. Tunnelling and Underground Space Technology, 49(3), 2015, pp.98-113.
20. Song, W. D., Cao, S., Fu, J., Jiang, J. G., Wu, F., “Sensitivity analysis of impact factors of pillar stability and its application”. Rock and Soil Mechanics, 35(S1), 2014, pp.271-277.
21. Yin, H. S., Wu, A. X., Li, X. W., “Orthogonal polar difference analysis for sensitivity of the factors influencing the ore pillar stability”. Journal of China Coal Society, 37(S1), 2012, pp.48-52.
22. Jiang, J. Y., Wang, Y. H., Yan, P., Zhao, Z. H., “Numerical simulation analysis of instability failure of coal pillar in mine room mining”. Journal of Shandong University of Science and Technology (Natural Science), 37(5), 2018, pp.27-33.
23. Fu, X.Y., Li, H.Y., Li, F.M., Li, S.G., Zhang, B., Li, H.J.,Wei, L.K., “Mechanism and prevention of strong strata behaviors induced by the concentration coal pillar of a room mining goaf”. Journal of China Coal Society, 41(6), 2016, pp.1375-1383.
24. Ghasemim, E., Shahriar, K., “A new coal pillars design method in order to enhance safety of the retreat mining in room and pillar Mines”. Safety Science, 50(3), 2012, pp.579-585.
25. Peng, S. S., “Coal Mine Ground Control”. New York: John Wiley & Sons Press, USA, 1978, pp.76-77.
26. Du, X. Z., Lu, J., Morsy, K., Peng, S. S., “Coal pillar design formulae review and analysis”. In: Proceedings of the 27th International Conference on Ground Control in Mining, Morgantown, USA: ICGCM, 2010, pp.254-261.



End of an era in South Derbyshire coalfield

LAST PIT IS TO CLOSE

DONISTHORPE Colliery — the last remaining pit in South Derbyshire —is to close in March.

620 jobs are to go after British Coal announced this week that the 133 year old pit would close on March 30, saying that the colliery has lost over £5 million in the last nine months.

British coal has offered 300 of the workforce the chance of jobs at Asfordby, Coventry, Daw Mill, Lea Hall and Littleton Collieries, but that leaves 320 without work.

"The coal board has told us that they will try to look after those who do not want to take redundancy by offering consequential redundancies at other pits," said Mr Colin Dennis UDM representative at Donisthorpe.

Unhappy

Consequential redun-

By Andy Rush

because their rates of pay have dropped through taking the surface job, said Mr Price.

Mike Presley who transferred from Rawdon Colliery part of the complex with Donisthorpe which closed at the end of last year said: "I thought I would be here for another two years, we didn't even get transfer money when I moved pits."

Michael Stevens 37, said "I'm taking the redundancy and finishing. This isn't the industry it was when I started."

Paul Teon a deputy for

pit deputies at Asfordby."

Donisthorpe resident Peter Pynton who has worked at Donisthorpe for 12 years says he is getting out even though he says the redundancy offer as "diabolical."

A spokesman for British Coal said: "The new national redundancy offer is exactly in accordance with the letter of the law."

Though the pit officially stops production on March 30, salvaging will continue until June/July this year.

● Bagworth Colliery the only remaining pit in North West Leicestershire and earmarked for eventual closure has broken coal production

End of an era…a look back at the coal industry in the UK

Coal International takes a look back in history and features the last remaining pit closure within South Derbyshire

Sinking at Donisthorpe was commenced in March 1871 by the father and son partnership of G. Checkland and G.E. Checkland. Two shafts were sunk, each 14 feet in diameter to the Main Coal seam at approximately 223 yards from the surface and intersecting the Little Coal seam at approximately 159 yards. The Main seam was 14ft. 6in. thick at this location. Large areas of coal were purchased or leased, the areas including Donisthorpe itself, Overseal, Netherseal, Stretton-en-le-Field and Clifton Campville.

The large financial outlay involved in the Donisthorpe undertaking put the Checklands heavily in debt. Faulting of the strata, steep dip in places of the seams and inundation were further problems, together with prosecutions by the Inspector of Mines. A limited company was formed in 1886 and this company deepened the shafts to 288 yards to reach the Stockings seam at 257 yards in 1890. This did not overcome the difficulties and the colliery was sold in March 1903 to a new Donisthorpe Company which put the concern under the control of the Moira Colliery Co. Ltd. This company were the major colliery owners in the Western Basin of the Leicestershire coalfields. They were also the major colliery owners in the South Derbyshire coalfield, of which the Western Basin coalfield was an extension.

DONISTHORPE COLLIERY

General view of colliery surface showing the chimney and No.1 Pit headgear. On the right is No.2 Pit engine house. Geoff Hayes 1977.

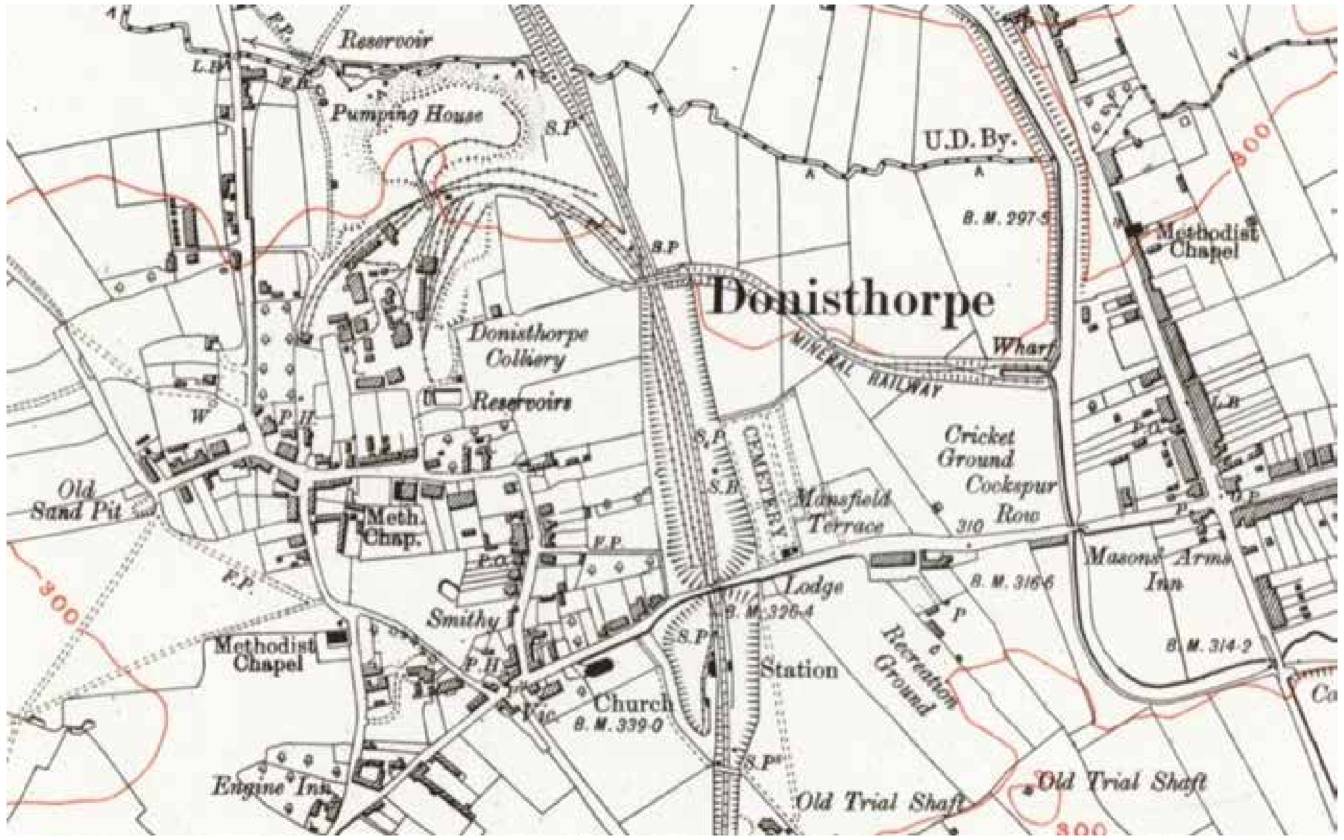
Rawdon aerial view.

The area of the take was now about two miles from north to south and approximately two and a half miles generally from east to west. On the eastern side, the workings were bounded by the Boothorpe Fault, to the south-west the seams outcropped, and the western boundary was defined by major faulting. Seam dips were not excessive except in the vicinity of major faults and near the outcrops where strata "drag" could cause inclinations of 1 in 1½.

Shafts – The two shafts were not sunk any further than the deepening's of 1890, i.e., the Stockings seam at 257 yards. No.1 Shaft was the downcast and coal winding shaft and No.2 shaft, was the upcast ventilation shaft for the colliery.

The original headgears were of timber and the No.1 shaft cage guides were of pitch pine. No.1 headgear was replaced in 1951 by a steel structure from the closed Netherseal Colliery. No.2 shaft also received a new steel headgear.

Winding – At No.1 shaft a twin-cylinder horizontal winding engine was installed by a now unknown builder. The engine was subsequently rebuilt with 26in. x 54in. piston valve cylinders, the piston valves being plain without any means of varying the cut-off. Gooch valve gear was fitted for reversing. The winding drum was parallel, 13 feet in diameter with a brake path on each side, acted upon by straight post brakes. Locked coil winding ropes, one and five-sixteenths inches diameter were provided. Overwind and overspeed protection was by a Melling's (Worsley Mesnes) pneumatic controller. Apart from the piston valves, the engine was typical 19th century with a flat bedplate and four-bar crosshead guides. Not long before the engine ceased work, the bedplate fractured and was repaired by metal stitching.



Amongst improvements carried out by the National Coal Board was the replacement in 1952 of 15 cwt capacity tubs by 3¼ ton capacity mine cars. The winding arrangements were altered so that a single minecar was wound in each cage. This resulted in improved winding times and the winding engine could perform 100 winds per hour from 257 yards. There was plenty of exhaust steam available and this was piped to a boiler feed water heater converted from an old Lancashire boiler. Other improvements by the National Coal Board included a new engine house built in the architectural style of the time, complete with a flat roof.

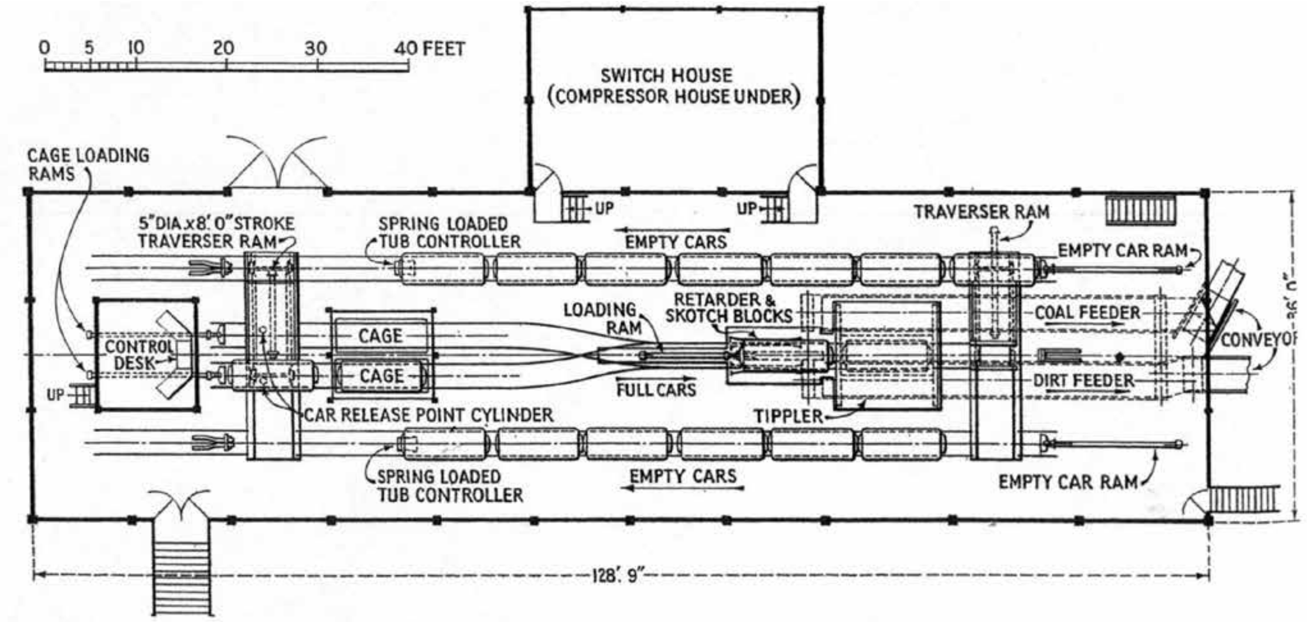
The engine was replaced in 1977 by an electric winder from another colliery. This could not better the winding rate achieved by the steam winding engine, 90 winds per hour being the maximum obtained.

No.2 Pit winding engine was a twin-cylinder horizontal and carried a plate denoting that it had been built by J. Jessup, London Boiler & Steam Crane Works, Leicester, although no date was specified. Originally built with slide valve cylinders, Worsley Mesnes Ironworks rebuilt the engine with new piston valve cylinders in 1916. Worsley Mesnes also put forward a proposal to prevent the engine bedplate from moving on its foundations. This does not appear to have been proceeded with and information is lacking on how this problem was resolved.

The colliery company suggested at this time that the steam pressure might be increased to 100 psi., but Worsley Mesnes considered that the engine bedplate was none too strong as it was and that the working pressure should be restricted to 80 psi. So, it remained until the end of the engine's working life.

As rebuilt the engine had 24in. x 48in. cylinders fitted with plain piston valves without any means of varying the cut-off. The piston valves were actuated by Stephenson's link motion. Structurally the engine had the traditional flat bedplate, which Worsley Mesnes had remarked upon as not being very strong, and four-bar crosshead guides. On the crankshaft was mounted a 12 feet diameter parallel

No.1 Pit headgear, engine house (left) and tops of boilers with main steam pipework. Geoff Hayes 1977.

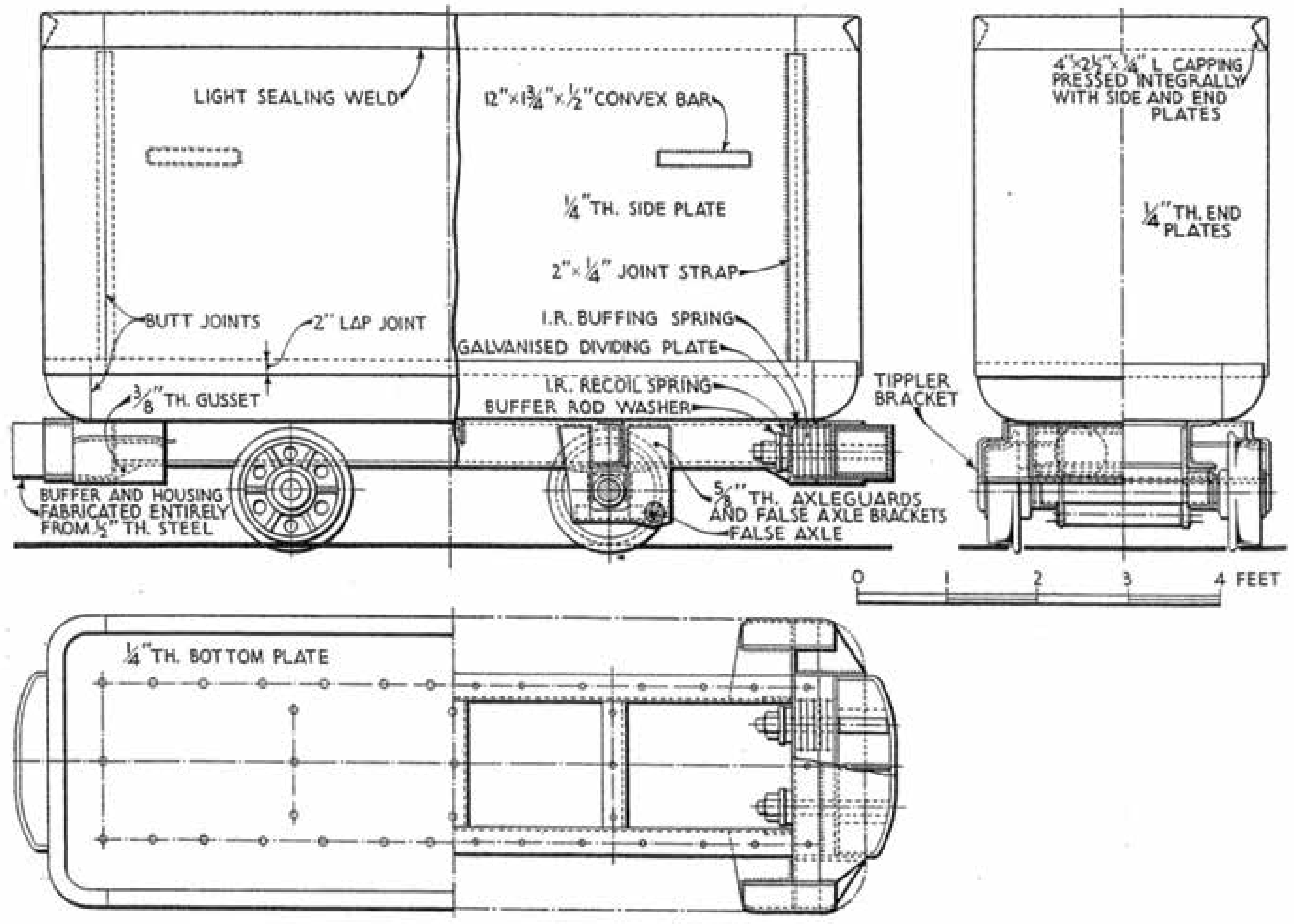


winding drum carrying 1¼ inch diameter locked coil winding ropes. Straight post brakes acted upon brake paths on each side of the winding drum. The brakes were operated by a Melling's (Worsley Mesnes) brake engine. Overwind/overspeed control was by a Melling's Patent pneumatic controller.

Under National Coal Board management, a very modern style engine house was erected around the engine, built-in brick and having a flat concrete slab roof.

No.2 Pit retained its steam winding engine until the closure of the colliery on 30 March 1990. Although the National Coal Board had enthusiastically gone in for electric winding, there was a long tail of steam survivors.

In 1952 a major improvement to the winding arrangements at No.1 Pit was completed. Coal was wound in 3¼ ton capacity mine cars made by Butterley and the mine car handling system was fully automated. The mine cars ran on 2ft. 6in. gauge tracks replacing 2ft. gauge 15 cwt



capacity tubs. The mechanical plant of the new scheme was made by W.H. Barker & Son (Engineers) Ltd, whilst the pneumatic equipment and electrical controls were made by the Westinghouse Brake & Signal Co. Ltd.

Changing of the mine cars in the cages at the pit top and bottom and placing mine cars in the tipplers at the surface was carried out by pneumatic rams engaging with a dummy rigid axle under the mine cars. No locomotives were employed and movement around the mine car circuit at pit top and bottom relied on gravity. Around the pit bottom mine car circuit the necessary elevation for gravity working was obtained by “creepers” between the rails. Lugs on the creeper chain engaged with the dummy axle under the mine cars.

The mine car handling systems at pit top and bottom were operated by one banksman at the pit top and one onsetter at the pit bottom. The control desk at each location was located in a control cabin. Boilers – Steam was provided by five Lancashire boilers working at 80 psi. and fitted with superheaters. In later years the boilers were fired by Danks’s chain grate mechanical stokers in conjunction with Danks’s automatic ash extractors. The forced draught was provided under the grates and there was an induced draught fan in the main flue to the chimney. The chimney was a circular section constructed in brick.

Boiler feedwater was drawn from the feedwater heater. Three Weir SIMPLEX vertical steam pumps were installed together with a standby electrically driven turbine pump. There was also a live steam injector which was supplied with cold water.

Ventilation – In the earlier years of the colliery a Waddle Patent fan was provided, and this may have been the initial means of ventilation at the colliery. By 1914, this fan had been replaced by a SIROCCO fan.

Pumping – A steam-powered pumping engine was initially provided. This had been replaced by an electrically driven pump by 1914.

Compressed Air – The compressed air required for the mine car handling systems at pit top and bottom was supplied at 60 psi by Westinghouse C.M.38 compressors. This type of compressor had originally been developed for use on the braking systems of electric railway rolling stock. The compressors were twin-cylinder single-acting self-cooled type which in colliery service were direct coupled to 10 horsepower AC squirrel-cage induction motors.

ix compressors were installed for the pit top equipment and three units for the pit bottom system. To supply the requirements of the pit top equipment, five compressors were adequate leaving the sixth unit as standby. To even out demand variations the compressors fed into a range of four 22 cu. ft. air receivers made by Messrs, Farrer of Newark-on-Trent.

Underground Transport – Transport of coal underground was entirely by conveyor belts by the early 1950s. Coal was fed by the conveyor system to a central loading point near the pit bottom where the coal was transferred to the mine cars for winding. The trunk conveyor was driven by a 140-horsepower motor taking alternating current at 3300 volts. The drive to the conveyor was transmitted by a Vulcan-Sinclair fluid coupling which allowed the motor to run up to 75% speed before picking up the load. Sequence controls were fitted throughout the system to ensure that the various feeder conveyors did not start until the main conveyor was running and vice-versa.

Materials were transported along the man-riding roadways from and to the No.2 shaft. Motive power was a 68HP Hunslet diesel locomotive.

Underground Working – As was usual in the coalfield, the Main Seam was extensively worked over the large area of “take” available to the colliery. Little knowledge is available of the early working of the colliery, but it would appear that both longwall and possibly pillar and stall working was employed.

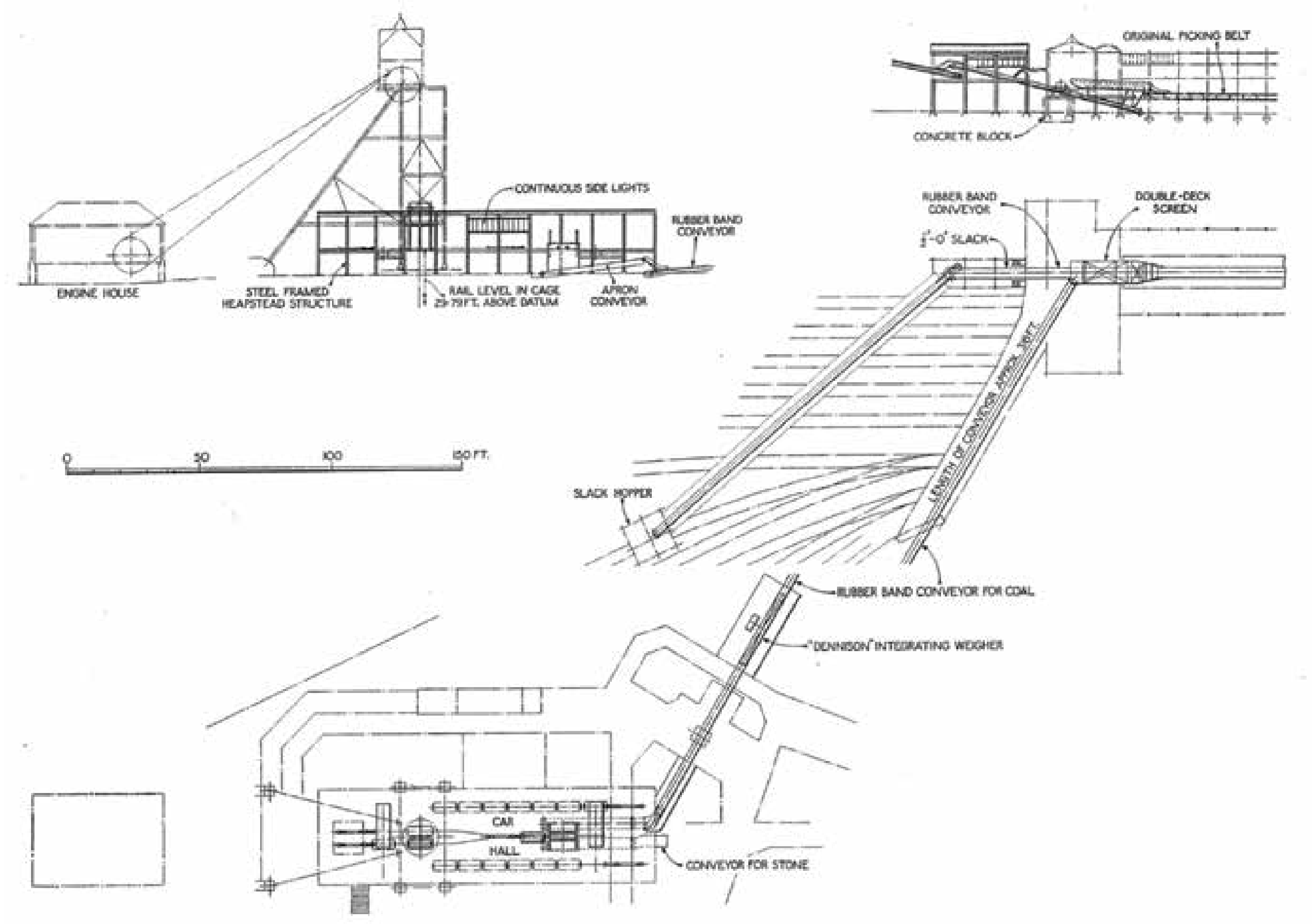
By the early years of the National Coal Board, the Woodfield and Stockings seams were being worked again over a wide area. The Woodfield seam was intersected at 240 yards in No.1 shaft. The Stockings seam was 8 feet thick of which 7 feet was extracted and the Woodfield seam was 4ft. 6in. to 5 feet in thickness. When being worked 6 inches of coal was left up as roof in the Woodfield seam. Fairly numerous small faults were present throughout the area and the Stockings seam was liable to spontaneous combustion.

Due to the closeness of these two seams extraction of one seam affected working conditions in the other. Generally, intake haulage roadways were driven in the Stockings seam with the return air roadways in the Woodfield seam. Advancing longwall faces were extracted in the Woodfield seam. When the boundary was reached retreat working was immediately commenced in the Stockings seam beneath the extracted area.

By the 1970s, old goaf areas of the worked-out Main seam in the Oakthorpe area had been re-entered. This was to win the large quantities of slack and small coal which had been thrown into the wastes in the early years of working. The old goafs containing the small coal, by now well crushed, were worked longwall retreat. The recovered coal was sold as power station fuel.

A Joy Continuous Miner machine was tried at Donisthorpe for headings in coal. This machine was worked on the American system of mining with a shuttle car carrying coal from the coal getting machine to a loading point on a conveyor belt. The machine was only suitable for thick seams, a feature of Donisthorpe Colliery, and there was at least some degree of success. A major drawback was that large quantities of small coal and slack were produced and the experiment at Donisthorpe was later terminated.

Coal Preparation – Coal leaving the pit-top tippler was delivered onto an apron feeder which elevated the coal for



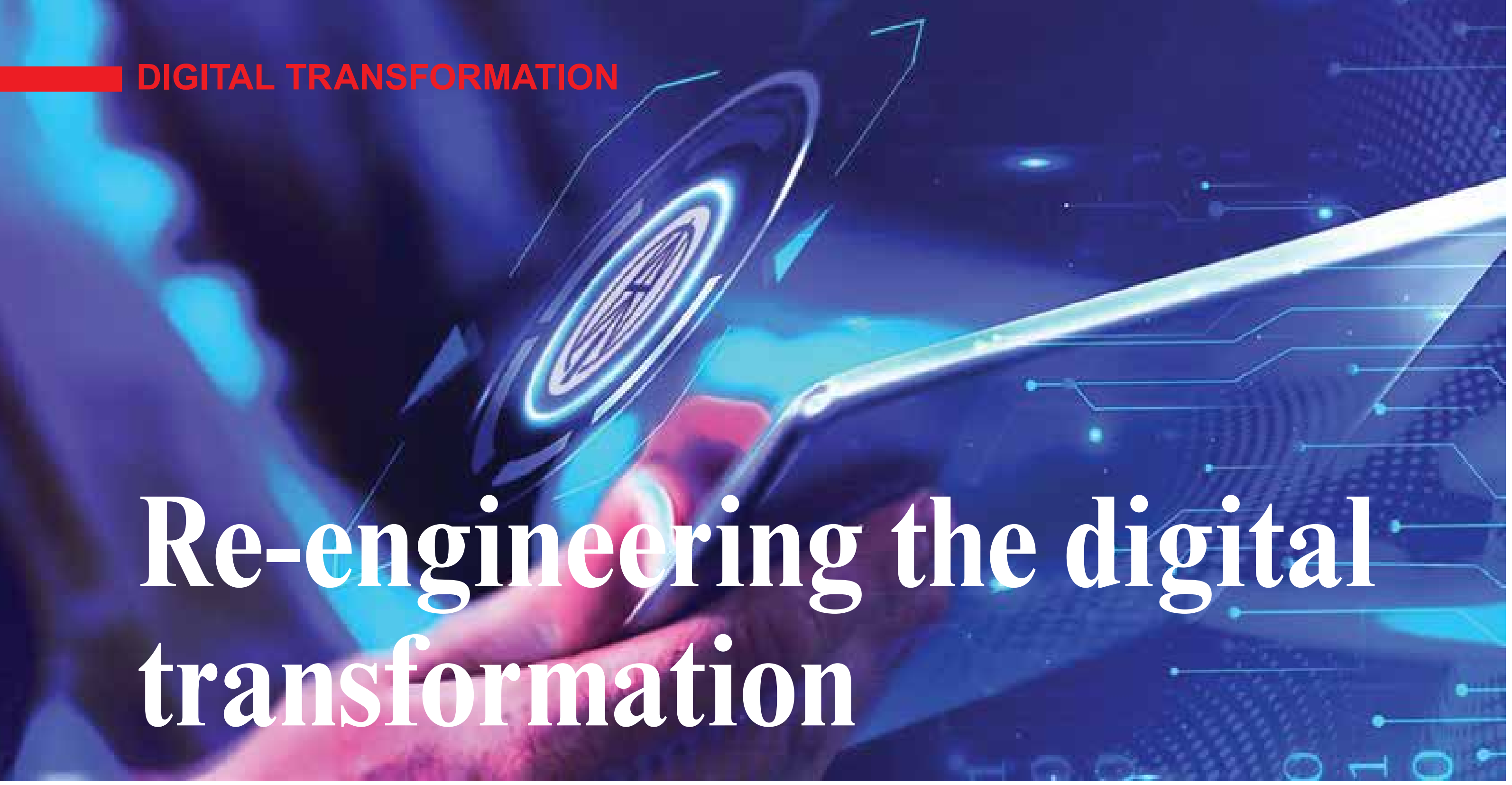
some 6 feet and discharged onto a chute which in turn fed a troughed conveyor belt for transporting the coal to the screening plant. Incorporated into the conveyor belt was a Blake-Denison totaler weighing machine.

At the screening plant, the conveyor delivered the coal onto a double-deck shaker screen. Coal more than 2-inch size passed over the upper screen and onto a 54in. wide plate-type picking belt from which the best coal and dirt were picked by hand. Coal not lifted from the picking belt was screened into nuts (2in. to 3in.), small cobbles (3in. to 4in.) and large cobbles (4in. plus).

Coal falling through the upper screen fell onto the lower screen, which had ½ inch diameter holes. Coal less than ½ inch in size was delivered onto a conveyor belt by which it was transported to a 90-ton slack bunker. Coal passing over the lower deck screen was further classified by size and passed through two parallel dry cleaners. Leaving the dry cleaners, the coal was delivered to overhead bunkers serving either railway wagons or road lorries.

Dirt wound from the pit was diverted on leaving the pit top tippler and transported by conveyor to an overhead bunker. This bunker discharged into 10-ton capacity side-tipping railway wagons for transit to the tipping site by shunting locomotive.

Coal International: Our thanks go to, Northern Mine Research Society Records and the South Derbyshire Mining Preservation Group for article content and photographs and the Geoff Hayes collection of photographs."Copyright South Derbyshire Mining Preservation Group.



Re-engineering the digital transformation

Processes and people alike must be upgraded to take full advantage of tools and technology.

The tools and techniques of digital transformation greatly simplify and speed up new product development. They are counterproductive and even senseless, however, if put to work supporting the "same-old, same-old" processes of product development, design engineering, manufacturing and service. The same is true for the processes used in every other business unit in the enterprise.

For project managers and enterprise leadership in digital transformation, the need for process modernisation should be obvious. Digital transformation's tools and techniques can greatly improve collaboration and innovation in new-product development, as just one example, but not until many existing processes are updated – or, as is often necessary, re-engineered. This is never simple.

Just as products are re-engineered to accommodate new capabilities, processes also must be re-engineered. Re-engineering is a proven way to address processes ill-suited to the trends and enablers of digital transformation; these can be large stumbling blocks for collaboration, productivity and even enterprise sustainability.

These views were spelled out in a recent virtual conference I participated in on process innovation and digital transformation ("PI-DX") run by Marketkey Ltd., a London-based business-information company focused on refining data into intelligence, business insights and innovation.

The panel focused on what Marketkey labels "legacy technical debt." The remedies discussed included process "modernization" and process "innovation," but problems in some processes run deep. These can only be addressed by re-engineering the process, ideally while replacing obsolete legacy systems and upgrading the technical skills of the workforce.

Process re-engineering is tied to digital transformation at several levels wherein information is freed from pre-operative formats such as spreadsheets, CAD-generated drawings and e-mail attachments; many critical processes are rendered obsolete.

Digital transformation requires up-to-date systems, tools, techniques and solutions; they can be difficult to work with. Amid new realities of data and information, these challenges require skills updates, too.

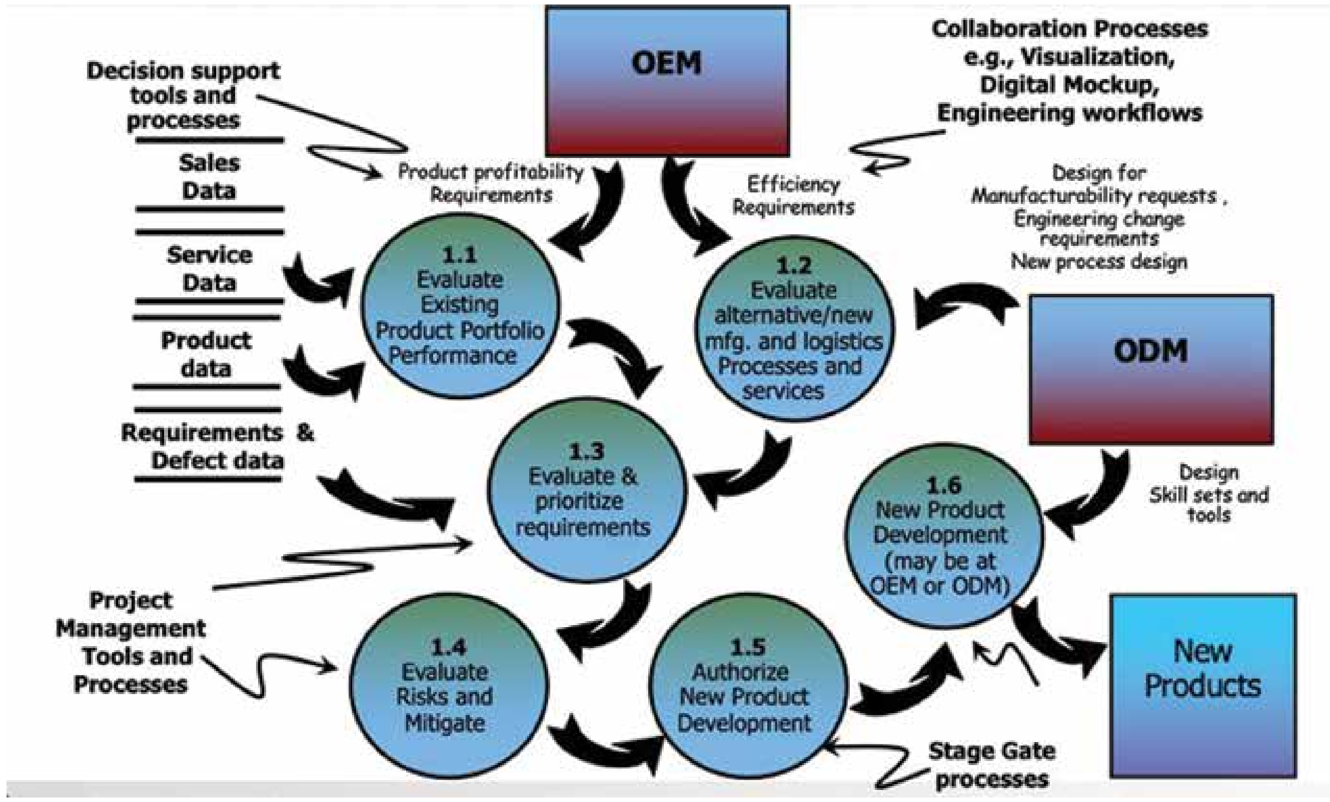
Processes that until recently were expected to change little have been demolished by technology and tech-savvy new workers, choosier customers, ceaseless innovation and shorter product lifecycles. Consequently, many long-established practices in the handling of information in processes are headed for the dustbin of digital history.

CHANGING THE THINKING

As goes information, so go the processes we use to search, use and manage it. Enterprises, business units and solution providers clearly see that their assumptions about many everyday processes have become questionable.

"The way we have been getting things done" no longer keeps up with the speed of innovation in today's marketplaces. And it is product and process innovation that helps fend off competitors, hang on to demanding customers and shore up profit margins.

Viewed in this light, it is little wonder that processes are being impacted in every product and asset lifecycle. These impacts are most disruptive in determining new



The complexities of how business units and enterprise processes fit together make re-engineering almost unavoidable. It also can lead to a reduction in those complexities.

product requirements and throughout design, engineering, production, service, and all data handling and information gathering tasks.

Users and managers also struggle with fallout from legacy systems and tools and the processes that support them. A pair of all-too-common examples:

- Reworking newly manufactured products at the ends of assembly lines, delaying shipment and running up costs
- Iffy, on-the-fly workarounds that turn into repetitive do-loops producing nothing but frustration

Both are good places to launch process re-engineering and easily win user support.

Re-engineering any process starts with a deep dive to pinpoint where and why things go wrong. Once the problems and their causes are clearly identified, address them one by one. So a big part of process re-engineering is developing new capabilities to reconfigure the tasks and sub-tasks that make up the process. Once these new capabilities are chosen, test and verify them. Though tedious, testing and verifying must be done with care.

Processes usually generate predetermined outcomes that support decisions or feed additional processes. Poorly planned changes to a process, or even to just a few of its tasks, could blindside workers elsewhere in the business unit.

In the enterprise's high-level business processes, the impacts of re-engineering run even deeper. These processes include concept to design, design to manufacturing, orders to cash and others that must not be overlooked.

A typical scenario for CIMdata clients takes shape while the processes are being re-engineered. After the process changes have been verified as viable, CIMdata continues to help the client while the re-engineered processes are put into use and, equally importantly, integrate the changes with other processes that are closely connected.

At this point, several crucial decisions must be made, and the synergy of outside expertise and knowledgeable staffers comes into force. These decisions focus on ensuring user buy-in as well as how best to gain the support of all those whose work is tied to the process(es) being re-engineered. Other key decisions cover lining up in-house technical resources and securing financial support.

CHANGING THE WORK PROCESS

A big part of the value of process re-engineering lies in helping the workforce grasp the benefits in letting go of obsolete processes. If the workforce is to welcome change and embrace innovation, make sure that decisions about re-engineering are clearly communicated.

An alternative approach to these communications is budgetary – putting business issues first. This means linking anticipated re-engineering costs to projected revenue gains.

To help with building your case for re-engineering a process, here are a few realities that must not be overlooked:

- Processes are linked in countless ways, even without the bidirectional and end-to-end (E2E) connectivity essential for maximum efficiency
- Process changes occur fast and often, prompting users to modify their processes themselves
- Process changes at the business-unit level are triggered by innovation such as augmented/virtual reality and advanced analytics
- Process changes also impact users directly – artificial intelligence and machine learning, for example
- At the enterprise level, processes are disrupted by model-based engineering, system-of-systems thinking, predictive analytics and agile software development

As the skills of the workforce are upgraded and transformed, new and better ways will be found to connect people, data, technologies and tools. As these are implemented, process re-engineering will grow in value – and inevitability.

Perhaps the best approach to process re-engineering is to undertake it together with workforce transition and skills upgrades. None of these crucial initiatives can achieve its full potential without the others. Transitioning workforce skills while re-engineering their processes can go a long way assure the ultimate success of digital transformation and, in turn, help secure the sustainability and long-term competitiveness of the enterprise.

Tom Gill *is CIMdata practice manager for PLM Enterprise Value & Integration. Prior to joining CIMdata in 2010, he was a PLM director in a Tier 1 US automotive supplier. Before that he had roles in CAD programming, engineering system administration and mechanical engineering.*

Author Tom Gill at work on a process re-engineering project.

Managing several stages of waste

The important issues on disposal of solid wastes from many mines is to choose the right varieties for the comprehensive utilization of mining waste and to control contamination from waste rocks and tailings. Environment friendly disposal of solid wastes from mines is the key pathway. It's no secret that mining can produce a lot of waste. This is evident by catching a glimpse of any mining operation and the scale at which they operate. In fact, in most cases, you'll likely only notice the actual mine waste because the majority of the actual operation is occurring underground. Mine wastes can be problematic due to the fact they contain hazardous material that can be released into the environment if not properly handled. Some of these hazardous materials include heavy metals, metalloids, radioactive waste, acidic water, and process chemicals.

Some of the extremely major problems and key challenges facing the contemporary world are shortage of resources and our ever-growing population and environmental pollution. With the development of the mining industry, mining exploitation activities have produced more and more solid wastes and induced increasingly grievous destruction on the environment. Waste rock, tailings and other solid waste are the largest industrial solid waste generated in the process of exploitation of mineral resources. A comprehensive utilization of solid waste from mines to compensate resources shortage and environmental protection will have enormous economic and social benefits.

Open pit mining has several stages of waste. First, to access the actual seams or veins of ore, the top layers of rock or overburden must be removed. Once the overburden has been removed, the seams can be extracted. When extracting the seams, there is additional waste rock that must be separated from the ore.

Waste rock or overburden refers to the often-large mass of initial soil and rock that is removed to get to the valuable mineral deposits. Typically, for every ton of ore that is mined, 5 tons of overburden is displaced. Overburden is not subjected to any chemical processes but must be removed to access the ore underneath. Overburden is managed by using it to resurface previously mined areas to revegetate and restore them to their original appearance prior to being mined.

MINE TAILINGS, WASTE, AND OVERBURDEN

GANGUE

Gangue is the worthless rock or material that is closely mixed with the valuable material to be processed. The separation of minerals from gangue is called mineral processing. More Occasionally, inefficient processing methods can produce gangue that still holds an ample amount of valuable minerals. As values of minerals increase, it can even be profitable to reprocess gangue to extract additional minerals that may have been missed during the first processing.

MINE TAILINGS

Tailings are finely ground rocks and other mineral waste as a result of mineral processing. Due to the way minerals are processed, tailings can contain concentrations of processing chemicals. This can make mine tailings an environmental concern, so proper transportation and disposal are crucial. Consequently, the next step is to pump mine tailings away with slurry pumps into tailings ponds. Tailings ponds are sedimentation holding ponds enclosed by dams and liners to capture and store the waste.

LIQUID MINE WASTE, MINE WATER

Mine water is produced in a few different ways at mine sites and can vary in levels of contamination. Water exposed to mining processes is also often acidic and can contaminate local water sources in a process called acid mine drainage (AMD) or acid rock drainage (ARD). Acid mine drainage is a heavy contributor to pollution of surface water across the globe. AMD is primarily caused when water flows over the sulphide-heavy material, forming an acidic solution. Water at mine sites is usually heavily monitored and management strategies are used to not only reduce the amount of mine water produced but also to treat the water before it is released back into the environment.

WATER TREATMENT SLUDGE

Sludge is produced at some mine sites and is similar to mine wastewater but has the additions of solids and processing chemicals. These additions turn the water into a more viscous sludge which can then be pumped away from the site. Since the majority of sludge has little economic value, it's essentially handled as waste. In extreme cases where the sludge is rich in harmful or radioactive material, it may be classified as hazardous waste and require special handling and disposal methods.

Mining is big business, but also one of the world's biggest polluters. A 2019 report estimated that operations produce over 100 billion tonnes of solid waste per year. The ratio of useful materials to waste minerals is staggering; waste mass can be several times that of base metals and can be millions of times that of rare elements such as gold.

Shamokin, PA is location of one of 80 mine fires burning across Pennsylvania.

This waste is of particular concern due to its often-toxic content, with poisonous materials such as mercury a frequent by-product of mining operations. Recent accidents, such as the collapse of a tailings dam at Vale's Brazilian operations near the town of Brumadinho, have also shone a spotlight on existing waste storage and treatment facilities, with growing concern that simply collecting vast reserves of solid and liquid waste is both unprofitable and highly dangerous. As demand for minerals, particularly rare earths, and other uncommon commodities, grows, this problem is set to only increase.

A promising counter to this growing problem is that of waste recovery. Rather than cutting down on waste itself, companies are investing in new industrial processes to extract and re-use some of the useful materials that are often dumped among tonnes of less useful mining waste. With platinum group metals (PGMs), base metals, and even rare commodities such as gold among these unintended by-products of mining, there are a number of initiatives across the mining industry to improve the reclamation of resources and push the sector towards a truly circular economy.

IMPORTANT LESSONS TO BE LEARNED

Drive through North-eastern Pennsylvania and you may see black hills of coal and orange water flowing near or through towns. What you're witnessing is the legacy of historic anthracite coal mining, which fuelled the USA's industrial revolution and two world wars, had extremely dangerous labour practices, and lead to the destruction of its landscape. Diverse hardwood forests filled with wildlife were replaced with black mountains of coal waste with acidic soil that can only support birch trees, briar bushes, and scrub vegetation. Thriving cold-water fisheries were replaced with abandoned mine drainage (AMD), orange water devoid of oxygen and all aquatic life.

While mining issues are gaining national attention since the 2015 Gold King mine spill in Colorado, Pennsylvania sometimes seems like the forgotten state despite having more mining issues than any other state in the nation.

Anthracite mining once fuelled the region's economy, but after coal companies began to go bankrupt, once-thriving towns were left with nothing but devastated land & water and the scattered spines of abandoned coal breakers & mine shafts. Land reclamation projects and AMD treatment systems help to alleviate some of these problems, but these solutions are often expensive. While mining issues are gaining national attention since the 2015 Gold King mine spill in Colorado, Pennsylvania sometimes seems like the forgotten state despite having more mining issues than any other state in the nation. Perhaps it's the fact that our mining heritage is in the past, while many other states continue to have active mineral and hard rock mining, allowing their issues to be more present.

The black hills of coal are more commonly known as culm piles. These piles are created by dumping coal waste, such as rock and shale, after separating it from the valuable anthracite coal. While these piles are large, they represent approximately 50% of what was taken out of the ground, revealing the massive size of mining voids lying beneath Pennsylvania's valleys.

Land reclamation generally involves bringing the land back to a natural contour, adding a layer of topsoil to encourage vegetation, and seeding the land in order to begin the reclamation process.

Land reclamation projects are mostly funded through state and federal grants, with EPA Brownfield Grants and PA Department of Environmental Protection Growing Greener grants allowing non-profits to help recover devastated landscapes. Land reclamation generally involves bringing the land back to a natural contour, adding a layer of topsoil to encourage vegetation, and seeding the land in order to begin the reclamation process. While this process is straight-forward, mining pits can be incredibly steep, making the reclamation process take longer and be more costly.

Shamokin, PA is location of one of 80 mine fires burning across Pennsylvania. AMD, or abandoned mine drainage, is another legacy of past mining. AMD flows from mine openings and drilled boreholes to relieve pressure from the underground mine pools. AMD forms when water reacts with pyrite, or 'fool's gold', deep in the underground abandoned mine workings.

As pyrite is exposed to water and oxygen, the sulphides within the rock react and break down to form sulfuric acid and iron oxide. Other metals and minerals within the rock can also become exposed and pollute the water, with many discharges in PA and other states containing heavy metals such as iron and aluminium, and some discharges containing trace amounts of harmful metals such as lead and arsenic.

Iron oxide swirls in a polluted stream. The iron removes most oxygen from the water and makes it impossible for most plants, fish, and insects to live in the water. AMD throughout NEPA is essentially rust and can be processed into a safe art pigment.

To put this into perspective, many mines were 500-1000 feet deep, with some mine shafts reaching approximately 2000 feet in depth. Like digging a hole in the sand at the beach, at a certain point water will keep filling the hole no matter how much you try to keep it out. It's the same with mine water. Once mining companies hit the water table, they would always have to pump water out of the mines, continually increasing the cost to produce anthracite coal. After all of the coal companies went bankrupt, along with historic events such as the Knox Mine Disaster in 1959 and the Historic Agnes Flood of 1972, deep mining ended in most parts of the Coal Region.

By the Agnes Flood of 1972 in which the Susquehanna River rose 40 feet and devastated the Wyoming Valley, most mining companies had claimed bankruptcy and as the pumps removing water were shut off, mine water began to spill out of any available opening leaving streets, basements, and streams filled with polluted mine water.

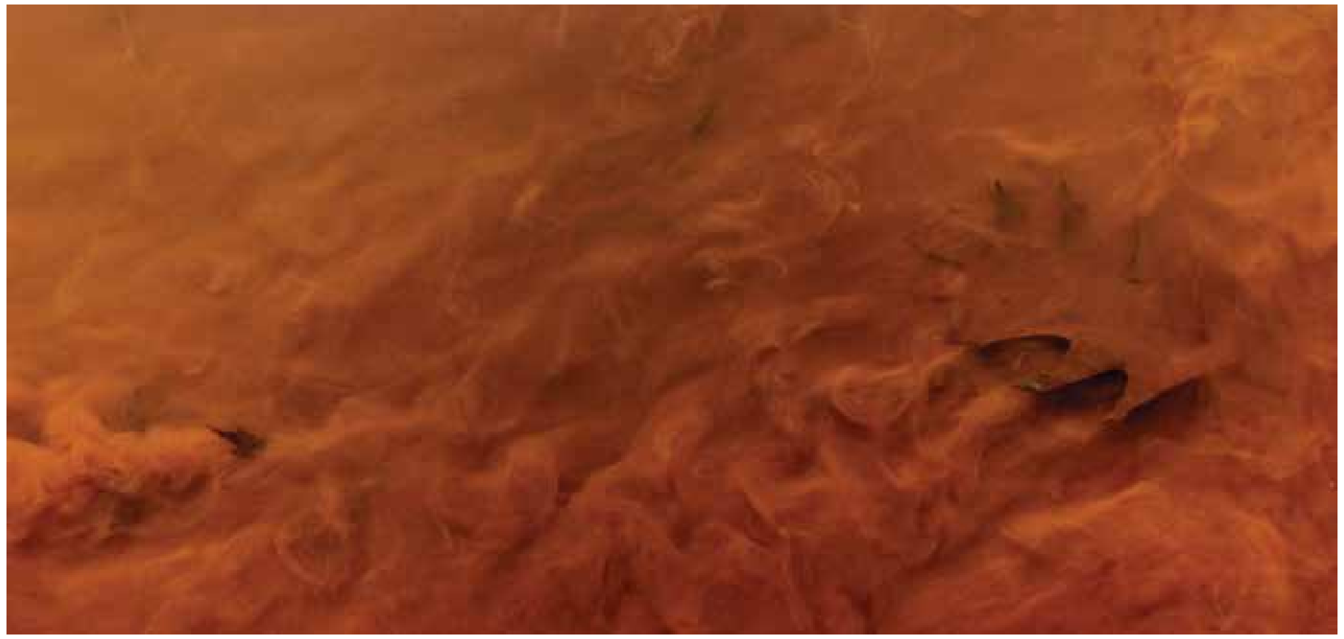
Furthermore, because mining companies were not required to treat abandoned mine drainage or reclaim mining land, once a company went bankrupt, the burden fell on taxpayers and government organizations to clean up the mess. Present-day active companies are required to reclaim land and treat any AMD discharges caused by their mining.

In Pennsylvania, AMD occurs in the Anthracite Region in the Northeast and the Bituminous Region in Western PA. In the Northern Anthracite fields, most AMD discharges have heavy concentrations of iron with relatively neutral pH's around 6.5, the same pH as normal rainfall. In the Middle & Southern Fields and the Bituminous Region, discharges tend to be more acidic (4 pH) with heavy concentrations of aluminium. Treatment systems help remove AMD and restore water quality. There are 2 types of treatment, active and passive. Active treatment refers to the use of added components such as chemicals (limestone) and machinery (oxygenation machines and automatic chemical dozers) to treat AMD.

Overall, treatment systems are expensive to install and even after successful installation, long-term upkeep can become difficult to fund and maintain.

In general, active systems are more costly and require electricity and regular maintenance to remain efficient. Passive treatment refers to the use of natural settling in large ponds for oxygenation as well as natural growth of wetland plants to treat AMD. Passive methods include settling ponds and using gravity to move water through a treatment system. These systems are usually more cost effective and don't have many long-term maintenance or operation costs. Overall, treatment systems are expensive to install and even after successful installation, long-term upkeep can become difficult to fund and maintain.

While this pollution problem will take a lot of effort to remediate, dedicated watershed associations, local conservation districts, and environmental non-profits are working to fix this problem by installing treatment systems, restoring streams, and educating the public about this issue through community events such as illegal dump clean-ups on mine lands and environmental education projects with community organizations and local school districts.



MINE TAILINGS, WASTE, AND OVERBURDEN

Pennsylvania's legacy of abandoned mine lands and AMD have implications nationally as well as globally. While clean energy is an important goal to achieve in order to help move towards a new era of environmental stewardship, coal mining communities need to be supported in the form of mine land and AMD clean-ups as well as economic stimulation in order to successfully move towards a better future.

Pennsylvania's mine land issues are a vast, far-reaching, and expensive problem. The effect can be seen nationwide, with other coal states such as Wyoming, Kentucky, West Virginia, and Illinois facing the same issues. Hardrock mining states also face similar issues, as seen with the Gold King Mine disaster in Colorado. Globally, countries like China, India, and Australia are just beginning to produce mass amounts of coal. Pennsylvania's legacy of abandoned mine lands and AMD have implications nationally as well as globally. While clean energy is an important goal to achieve in order to help move towards a new era of environmental stewardship, coal mining communities need to be supported in the form of mine land and AMD clean-ups as well as economic stimulation in order to successfully move towards a better future. Pennsylvania's struggles can serve as an example for other communities throughout the United States and developing industrial countries.

MINEWORX MOVES TO PILOT PLANT

Canada-based Mineworx has been involved in the mining industry for some time, having entered into the sector in 1975 with the acquisition of the Cehegín iron ore project in Spain, which produced four million tonnes of ore in its first fourteen years of operation. Since then, the company has moved into the development of more advanced technologies, aiming to increase the environmental viability of both its operations in particular and mining in general. The business reached a major milestone recently, when it announced an agreement with Tennessee's Davis Recycling Inc. to construct a pilot plant; the operation will see platinum group metals (PGMs) recycled from used catalytic converters.

The project will see the miner enter into a PGM recovery business that it values at around $30bn annually, and the move is a critical step in demonstrating the efficacy of the technology, which builds on the work of another partner, EnviroLeach. This third company has developed a water-based process to extract PGMs from catalytic converters, with up to 90% of the precious metals being recovered. The process removes the need for harmful substances, such as cyanide, to be used in the extraction process, which have been an industry standard but pose significant risks to human health and environmental safety.

This collaborative approach could help share information that could be beneficial across the mining industry, a sector which could see an increased demand for innovative waste treatment in the future. EnviroLeach notes that global electronic waste is predicted to increase to 78 million tonnes by 2026 as electronic devices become more widespread, and demand for gadgets increases.

COMSTOCK TARGETS MERCURY REMOVAL

Another mining company targeting a particular mineral is Comstock Mining, a Nevada-based miner that aims to improve the recovery and removal of mercury from mine tailings. The poisonous metal has long been a source of public health concerns in both artisanal mining and large-scale operations. A 2018 report found that over 1,000 tonnes of mercury was produced in the artisanal gold mining sector, due to the metal's use in separating gold from non-precious ores. Notably, the waste that flooded the town of Brumadinho in the infamous Vale tailings dam collapse was found to contain dangerous quantities of mercury, arsenic, and manganese.

Considering these dangers, and the widespread nature of mercury in the mining industry, Comstock's work could prove beneficial for miners across the sector. The miner owns the Comstock Lode, a gold and silver deposit that was first mined in the mid-19th century and saw almost $4m in investment from the company in 2018. The company plans to use this deposit to test a pilot mercury clean-up operation, backed by technology firms Mercury Cleanup and Oro Industries.

The joint venture will see the construction of a two ton per hour pilot plant to treat the 15 million pounds of poisonous mercury that have been produced over the course of the Comstock Lode's mining life, and a successful operation could demonstrate a way forward for a mining industry that still struggles with mercury production.

VTT'S COLLABORATIVE PROJECT

Many of these mine waste projects are collaborative in nature, and this is especially true for VTT's MetGrow+ project, a collaboration with 19 companies, research organisations, and universities from nine European companies. The project was a four-year, $8.7m initiative to find ways to improve recovery of a number of waste minerals, such as cobalt, nickel and zinc, and improve Europe's self-sufficiency with regard to metal production. The project focused more on supply chain optimisation than technological innovation, and VTT reports that miners could see waste mineral recovery increased by up to 20% by following the initiative's recommendations.

A key challenge for the project was developing a robust framework that could be applied to the mining industries of several European countries, each with a different balance of mineral exports and imports. The researchers overcame this by developing the "MetGrow Calculator", an online tool that works out the optimal waste recovery process for a mine or region based on characteristic input by the user. VTT claims this system can consider factors such as local access to mineral reserves and will recommend an appropriate waste management system.

In addition to supply chain optimisation, the researchers completed work into the best uses for residual material from which metals have already been recovered. VTT noted that many recovered materials can be repurposed for use in building by being reworked into concrete, highlighting the project's broad scope and attempts to improve efficiency across the breadth of the mining and construction industries. Scandium International seeks industry support.

A project at an earlier stage of development, and one seeking, rather than benefitting from, industry support, is Scandium International's ion exchange project. The initiative will use ion exchange technology, a process usually used in the purification of drinking water, where ions are moved between two electrolytes to separate a compound into its component parts.

Scandium International expects to extract cobalt, nickel, and copper from mining waste. The miner also noted that the technology could be used to extract other minerals, such as rare earth elements, but that this would depend on the financial viability of the process itself.

This need to demonstrate technological and economic viability is a key challenge for Scandium International, and it has put out a call for copper miners and processors to sign up for involvement in the project. The miner seeks a partner with a functional copper plant, which can be used to demonstrate the efficacy of the technology on a demonstration scale, before being scaled up to larger productions, or expanded to include other resources.

Scandium International is particularly reliant on this external support considering its own limited mining resources. The company has just completed a feasibility study on its Nyngan scandium mine in New South Wales, Australia, and is a firm with big ideas and significant belief in new technologies, but perhaps lacks the material facilities to put many of these ideas into practice.

MINT INNOVATION'S "BIO-REFINERIES"

Moving from theory to practice is a similar challenge faced by Mint Innovation, a New Zealand technology start-up that uses microorganisms to recover metal from waste streams. The technology is unlike anything else in the mining sector, with the company envisioning a "bio-refinery" to recover gold from waste in a two-stage process. First, a traditional leaching process removes base metals such as iron and copper from electronic waste, before a patented acidic compound is applied to the waste, strong enough to dissolve gold that is then absorbed by microbes in the compound.

While gold is Mint's first objective, the technology has uses across the mining industry, with the microbes able to absorb palladium, platinum, and rhodium with minimal chemical alterations. The start-up is also bullish about the scalability of its solution, relying on a business model where local recyclers help collect electronic waste and aid in distributing the recycled materials, potentially enabling the company to build its bio-refineries in any city with significant electronic waste with minimal up-front costs.

While the technology needs further development, namely in finding a way to recycle the chemicals used in the gold-absorbing compound, and the start-up is still in search of a financial backer to help realise its lofty ambitions, Mint's work is an example of innovative and technologically driven solutions to a sector that is still struggling to clean up its waste management.

As the mining industry uses large volumes of water under greater environmental scrutiny, operators are finding innovative ways to strain, treat, and reuse water that accumulates in pits, sumps, and wash bays more efficiently.

In the industry, heavy equipment wash downs are a major source of water use. Wash processes are used to clean mud, clay, and other corrosives off mining machinery, trucks, and other heavy-duty equipment. The wastewater is typically collected in a service bay or sump and must be sufficiently strained and treated before reuse.

When rainwater washes over equipment and open pit mine sites, it can also generate water mixed with dirt and sediment that is typically collected in a large sump or pit nearby. In underground mines, groundwater infiltration and condensation can cause a similar effect to that of rain.

No matter how the water is generated, any dirt and debris must be removed before it can be used, further treated, recycled, or discarded. Due to the volume of water used, the mining industry is increasingly seeking new ways to reuse water through more efficient filtration, treatment, and recycling efforts.

Toward this end, the mining industry is finding that automated scraper strainers are one of the simplest, most cost-effective methods to remove both micron-sized particles and oversized dirt and debris. This is helping to streamline water straining for immediate re-use. It also provides a critical first step in multi-step water treatment systems that can reduce clogging, fouling, and maintenance while increasing production.

MINE TAILINGS, WASTE, AND OVERBURDEN

One example is the automatic scraper strainer from Acme Engineering, a North American manufacturer of industrial self-cleaning strainers. The motorized unit is designed to continually remove both very large and very small (100 micron) suspended solids from water that can accumulate in a mine, pit, or sump. Cleaning is accomplished by a spring-loaded blade and brush system, managed by fully automatic controls.

Four scraper brushes rotate at 8 RPM, resulting in a cleaning rate of 32 strokes per minute. The scraper brushes get into wedge-wire slots and dislodge resistant particulates and solids. This approach enables the scraper strainers to resist clogging and fouling when faced with large and high solids concentration. It ensures a complete cleaning.

Blowdown occurs only at the end of the intermittent scraping cycle when a valve is opened for a few seconds to remove solids from the collector area. Liquid loss is well below 1% of total flow.

The technology is even being used to filter and reuse water from a virtually unused resource– accumulated water at the bottom of mines, which until now has mostly been an impediment to efficient production.

"Automated scraper strainers are being used to remove rocks and suspended solids from the water that usually collects at the bottom of mines. The filtered water is then pumped back to the surface for continual reuse," says Robert Presser, Vice President of Acme Engineering, an ISO 9001:2015 certified manufacturer of environmental controls and systems with integrated mechanical, electrical and electronic capabilities.

According to Presser, to increase reliability in rugged mining conditions, the industry is using the automatic scraper strainer in an innovative way with an eductor, a type of pump that does not require any moving parts.

"Mine operators are using an eductor at the bottom of the strainer to pressurize the blow down line to send the evacuated solids [from the strainer] relatively far away. Since the eductor has no moving parts, operators don't have to worry about small bits of rock and particles damaging an impeller like they would on a typical pump," explains Presser. He adds that operators must use a ¾-inch low flow water line at about 75 PSI to inject motive water into the eductor to move the solids down the blowdown line.

As mining operators seek to comply with environmental standards and do more with less, those that take advantage of advanced strainers to reuse their existing water most efficiently will cost effectively achieve both these aims while improving their process.

Dust suppression in Chinese coal mines

This article looks at the development of dust removal, where dust removal efficiency is poor and water usage is wasteful in relation to wet dust removal devices commissioned in headings and coal faces in underground mines. The development of coal mine mechanisation, information, data collection and automation provide opportunities for the development of intelligent dry dust collectors.

One of the main purposes of this article is to develop flame-retardant anti-static dust removal filters, which can increase the effective dust removal filter area by more than 20% and have a total dust removal efficiency of more than 99.5%, in conjunction with this development aspect there is a need to greatly reduce the overall size of the dust collector and apply automatic intelligent control technologies linked to coal face and heading machinery.

With the widespread application of mechanized excavation technology and equipment in mines, the heading face has become the primary source of underground dust. At present, most of the heading working faces use spray devices or wet dust collectors as dust reduction and dust removal measures. The dust removal rate is about 70%[1], and the efficiency is low. It is difficult to remove the respiratory dust below 5 μm on the working face. The average daily water consumption is 10t, which is a serious waste of water resource, causing secondary pollution of water, and drainage is also difficult. Some mines have begun to apply dry dust collectors, which can filter 0.5μm or even smaller respiratory dust without water, and do not affect the working environment of the working face.

However, the level of intelligence is relatively low, without any unmanned intelligent control functions, such as fault self-checking and alarm, automatic blowing and control adjustment, and automatic start and stop.

By the year of 2022, the proportion of large-scale coal mines in the country will have reached more than 70%. The level of mechanization, informatization, automation and intelligence of coal mines will be greatly improved, and the number of intelligent heading faces will be up to 1,000. So there is an urgent need for supporting intelligent dry dust collectors. We need to develop an intelligent dry dust collector to analyze the running status of the heading machine, the environmental dust concentration and other parameters, to realize the automatic start and stop of the dry dust collector; according to the resistance change, it can automatically adjust the cleaning time and frequency of the filter element air cleaning device; it can judge the operating conditions of the filter element and air cleaning device of the dust collector in real time, so as to send out warning information to the monitoring personnel and notify the maintenance personnel in time for equipment maintenance; and it can timely report the fault records and operation records to the maintenance personnel to realize unmanned operation.

DEVELOPMENT OF DRY INTELLIGENT DUST COLLECTOR

In order to meet the requirements of large limitation of working space, air humidity above 90%, and CH4 explosive environment in coal mine's underground tunnels, the underground dry intelligent dust collector in coal mine utilizes the principle of negative pressure filtration, and sets exhausting fan to generate negative pressure, so the dust-laden air on the working surface is sucked into the main body of the dust collector. And then the clean air is discharged into the tunnel through the filter course of the dust removal filter element. The equipment structure is mainly composed of the main body of the dust collector, flame-retardant and anti-static filter element, filter element cleaning mechanism, explosion-proof exhausting counter-rotating fan, and intelligent monitoring system. The main structure is shown in **Figure 1**.

The main body of the dust collector is designed as a long and narrow structure. The intelligent monitoring system complies with the GB3836 electrical explosion-proof national standard. The flame retardant and anti-static performance of the dust filter element is free from the humidity underground.

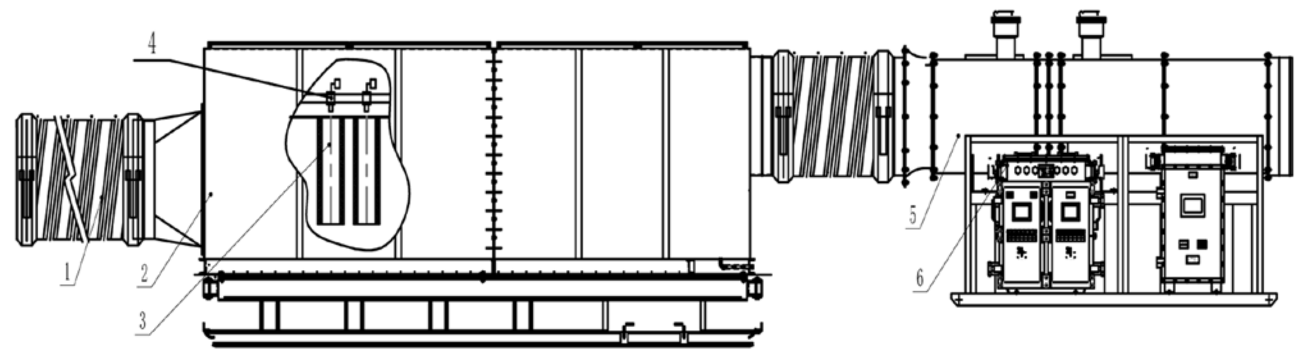
The main body of the dust collector

The main body of the dry dust collector adopts an open air inlet and is equipped with an air flow guide mechanism to avoid internal turbulence, so that the dust removal load of the filter element is uniform, and the operation efficiency of the dust collector is improved[2]; the dust removal filter element adopts the vertical rapid pull-out installation of the upper box, with the squeezable rubber seal, which makes it easy to replace and maintain the dust filter element; the dust removal box has a modular structure – the main body can be disassembled into multiple sections, connected by flanges, and can be enlarged at any time according to the different dust removal air volume of the dry dust collector, so as to meet the requirements of dust removal air volume in different heading faces, and to be convenient for transportation and installation in coal mines; the main transport modules are diversified, and can be equipped with caterpillar automatic migration, traction of heading machine's sliding boot base, and pneumatic monorail hoisting migration according to the specific requirements of different coal mines.

Flame-retardant and anti-static dust removal filter element

The filter material of the dust removal filter element uses chemical fibre with an oxygen index greater than 30 as the base material, and conducts the impregnation treatment of conductive particles to make the particles distribute on the fibre of the filter material evenly, so that the conductive resistance of the filter material is less than 3 × 108 Ω, and a new type of material without rolling points can be developed through the combination with the ne w production process, as shown in **Figure 2**.

The biggest difference between this chemical fibre material and the traditional hot-rolled non-woven fabric is that there is no nip point. The traditional non- woven fabric uses a roller with a large number of bumps evenly distributed to



1. Negative pressure air duct; 2. Main body of the dust collector; 3. Flame-retardant anti-static filter element; 4. Filter element cleaning mechanism; 5. Explosion-proof exhausting counter-rotating fan; 6 Intelligent monitoring system.

Figure 1: Structure of underground intelligent dry dust collector in the coal mine.

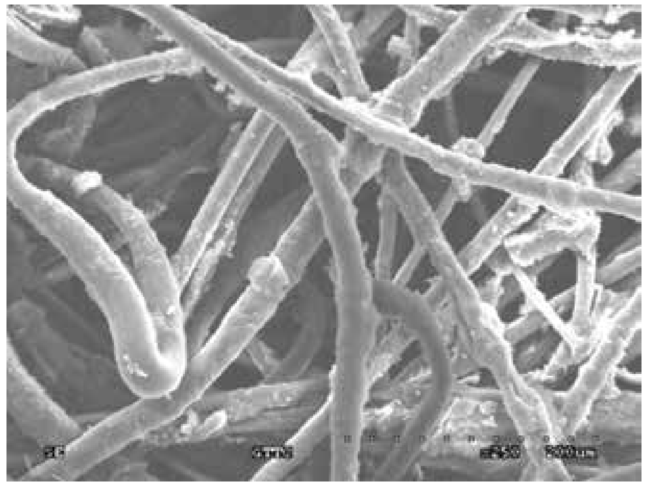


Figure 2: Microscopic view of chemical fibre without rolling points.

press and seam it, so the processed non-woven fabric has a large amount of evenly distributed nip point s on the surface. There are no micro-pores on the points, and the filtering effect will be lost. Normally, the total area of the rolling points accounts for at least 20% of the cloth surface area3; namely, the effective filtering area of the traditional filter material is actually reduced by more than 20%, while the new processed filter material adopts smooth roller on rolling filter material, and the effective filter area can reach 100%, which greatly reduces the material cost. At the same time, PTFE membrane is applied to the surface of the new chemical fibre filter material to make the surface filtration accuracy reach 0.3 μm, and a very stable initial dust cake is artificially set on the surface of the filter material to protect the filter material without clogging the fibre pores, thereby reducing filter resistance. Because its surface is very smoot h, and the tension is very low, it is easy to blow and clean, and both the accuracy of the filter material and the service life of the filter material are comprehensively improved[4].

The filter material is folded into folds and enclosed into a cylindrical shape to form a large-area and compact pleated filter element, which is equipped with a metal support frame and glued with the upper and lower end covers. The upper end of the end cover is installed with a sealing ring that seals the dust removal box. With comprehensive consideration of such factors as filter area, dust removal effect, dust removal box volume and other factors, the dust rem oval filter element is designed to be 8 times the filter area of filter bag in the same size, and the filter area reaches more than 12m2.

Filter element cleaning mechanism

The principle of the filter element cleaning mechanism is to blow a large amount of clean compressed air into the inner side of the filter element, the leeward side, in a short period of time, which causes the filter element to rapidly expand and produce deformation and vibration. Under the dual effects of reverse air blowing and vibration, the dust attached to the windward side of the filter element flakes off and falls into the dust collection device. Its structure is mainly composed of compressed air filter, air storage tank, electromagnetic pulse valve, blowing pipe, and Venturi inducer, as shown in **Figure 3**.

The compressed air provided by the underground compressed air pipeline in the mine is stored in the air storage tank after filtering the water, oil and dust of the filter. When the filter element needs to be cleaned, the electromagnetic pulse valve of the intelligent control system controls will open, and the compressed air will pass through the blowing outlet of the blowing pipe. When it blows into the inducer, the sucked surrounding air and compressed air form a positive airflow to remove the dust from the windward side of the filter element[5].

The air storage tank has a pressure-stabilizing effect on the pulse blowing cleaning mechanism. The larger the volume is, the more stable the air source pressure will be, and the better the cleaning effect of the filter element can be. However, limited by the size of the equipment, the minimum volume of the gas tank can be calculated based on the maximum air consumption of the pulse valve in one blowing and the pressure loss of the gas tank less than 30% after the pulse valve blowing . This mine arranges the blowing pipes of the dry dust collector horizontally. Its pipe diameter is consistent with that of the outlet pipe on the pulse valve, while its length is shorter. One single pulse valve blow and clean relatively a small number of filter elements. The area of the nozzle is evenly distributed, in accordance with 60% of the outlet pipe diameter area of the blowing pipe.

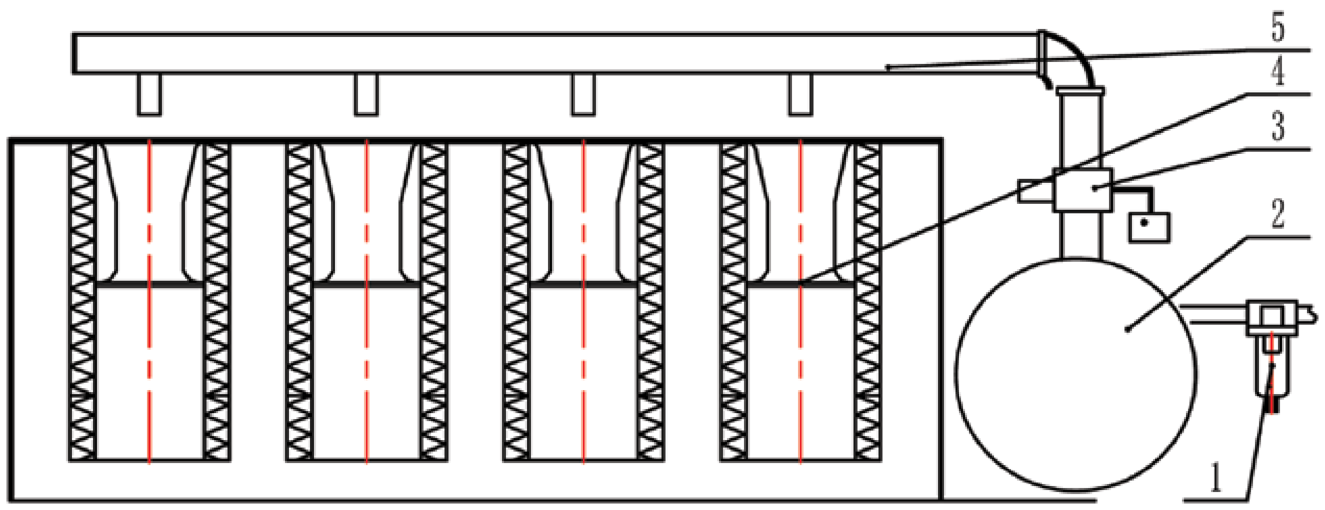


Figure 3: Schematic diagram of filter element cleaning mechanism.

DUST SUPPRESSION

Intelligent monitoring system

According to the interaction and influence relationship of the heading machine working status, compressed air pressure, filter element pressure difference, dust concentration and other data at the heading face and the performance of the dry dust collector, we design the intelligent monitoring system that takes the programmable controller as the control core, and the parameters such as the power feed detection, pressure, pressure difference and dust concentration as intelligent feedback.

After program processing, the system can automatically control the start and stop of dry dust removal device, intelligent cleaning, fault detection and alarm, and intelligent control of an unattended operation[6-7],the structure of intelligent control system is shown in **Figure 4**. The upper computer of the intelligent monitoring system provides complete data services, integrating storage, query, report, and web publishing functions, and supports the access and query of terminal devices such as mobile APP, tablet computers, various computers and touch all-in-one machines.

According to the motor operating parameters of the heading machine through RS485 telecommunication monitoring, when the load of heading machine reaches the critical value of the tunnelling operation, and the dust concentration of the heading end reaches the pre-set value, the auto-control electromagnetic starter will start the dry dust collector for dust removal, and the running power of the dust collector fan will be fed back to the programmable controller at the same time, linked with the heading machine in real time; according to the maximum working resistance of the dust collector, a safe value is set. When the pressure difference of the filter element reaches the safe value, the electromagnetic pulse valve is sequentially activated to clean the dust filter element, and by calculating and comparing the rate at which the resistance of the filter element reaches a safe value, the blowing frequency of the electromagnetic pulse valve is automatically adjusted, so as to ensure the cleaning efficiency of the filter element; when the air storage tank is

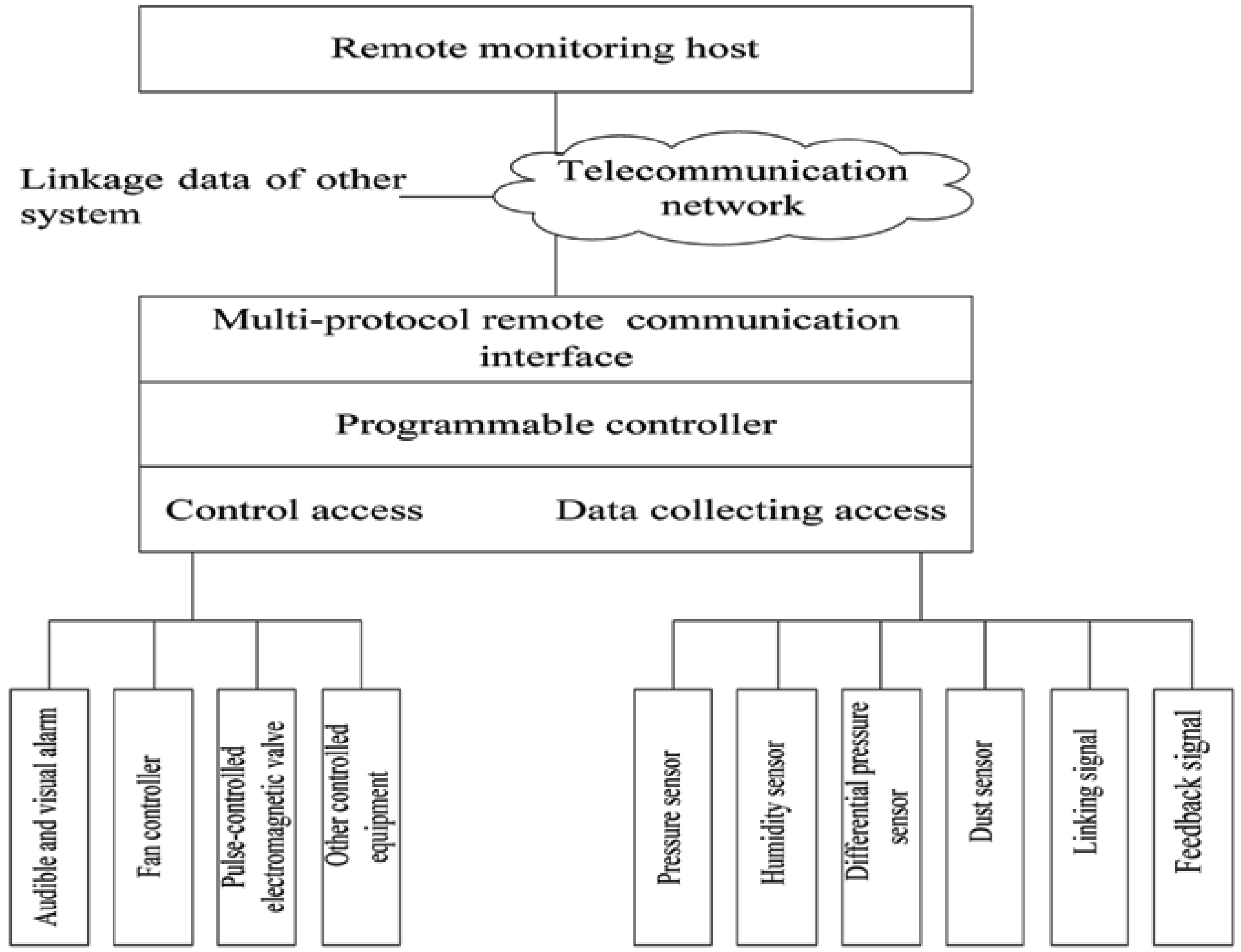


Figure 4: Structure of intelligent control system for dry dust collector in coal mine.

under pressure for 1 minute, or the filter element pressure difference exceeds the maximum value of 2000 Pa, or the electrical parameters of the exhausting counter-rotating fan are abnormal, or the value of the dust sensor in the outlet air flow increases suddenly, or the like, the alarm will send out the failure information of the air supply system, the blowing system, the dust removal power system, the filter element damage or the seal leakage, etc., and the fault data will be sent back to the remote monitoring center to remind the monitoring and maintenance personnel to carry out checking, repairing and maintaining; through the multi-protocol communication interface, the remote monitoring host is connected to the mine underground communication network to exchange data with other related systems, so that the multi-system coordination and linkage can be realized, which analyses the operating status parameters of the mine's underground dry dust collector through the remote monitoring center, updates the operating program, so that the operating efficiency of the dust collector is continuously optimized, and the real unmanned tunnelling face is realized. The above functions are verified by the intelligent control system by means of artificially setting networking of the boundary points and fault points.

After linkage actual tests of the functions, actions, and unmanned one-key start for 100 times, the system reliability can be up to 100%.

MAIN PERFORMANCE TEST

Flame retardant and anti-static performance of filter material The dust removal materials in coal mines have passed the test after flame-retardant and anti-static treatments, relying on the Quality Supervision and Inspection Center for Coal Mine Explosion-proof Safety Products, in accordance with the MT 113 general test method and determination rule for flame-retardant and anti-static properties of polymer products used underground in coal mines. The flame-retardant test data are shown in **Table 1** and **Table 2**, and the surface resistance testing data can be seen in **Table 3**.

Table 1: Burning test of alcohol blast burner.

Sample	Time of flame combustion (s) The maximum is 10s, and the average is not more than 3s.	Time of flameless combustion (s) The maximum is 30s, and the average is not more than 10s.	Flame extension length (mm) The maximum is 280mm.
1	2.5	1.5	160
2	2.3	1.0	162
3	2.8	1.7	178
4	3.2	1.8	218
5	3.0	1.5	178
6	2.0	1.2	173

According to the analysis of the above data, in the alcohol blast burner test, the maximum time of flame combustion is 3.2 seconds, and the average is 2.63 seconds, while the maximum time of the flameless combustion is 1.8 seconds, the average is 1.45 seconds; and the maximum length of flame extension is 218mm. According to the MT 113 objective criterion, it is in line with underground use requirement in coal mines.

Table 2: Burning test of alcohol burner.

Sample	Time of flame combustion (s) The maximum is 12s, and the average is not more than 6s.	Time of flameless combustion (s) The maximum is 60s, and the average is not more than 20s.	Flame extension length (mm) The maximum is 250mm.
1	2.4	1.2	155
2	2.6	1.0	150
3	2.0	0.9	140
4	2.8	1.2	160
5	3.0	1.4	180
6	2.2	1.0	144

According to the analysis of the above data, in the alcohol burner test, the maximum time of flame combustion is 3.0 seconds, and the average is 2.5 seconds, while the maximum time of the flameless combustion is 1.4 seconds, the average is 1.12 seconds, and the maximum length of flame extension is 180mm. The test results exceed those in the MT 113 objective criterion.

Table 3: Surface power resistance test.

Sample	The upper surface resistance No more than 3.0×108Ω on average	The lower surface resistance No more than 3.0×108Ω on average
1	$2.3\times10^{3}\Omega$	$1.2\times10^{3}\Omega$
2	$6.5\times10^{3}\Omega$	$2.2\times10^{3}\Omega$
3	$2.6\times10^{3}\Omega$	$2.5\times10^{3}\Omega$

According to the analysis of the data in Table 3, the average resistance on the upper surface of the filter element material is 3.8 × 103 Ω, and the average resistance of the lower surface is 1.97 × 103 Ω. The resistance grade is much lower than 108 Ω, and the anti-static performance fully meets the requirements.

Dust removal performance test

This experiment took 906 heading working face in Daxing Coal Mine with the dust concentration of 1000 mg/m3 – 1800 mg/m3 as the testing range, selecti ng 12 samples randomly for test, and the filter method was used to test the dust removal efficiency. The 500m3/min coal mine underground intelligent dry dust collector was the Test host, an d fan performance test C-type device served as test platform, equipped with DYM3 empty box barometer, ventilation psychrometer, YJB-2500 compensation micro-manometer, U-shaped differential pressure instrument, dust sampler, AFP-8A pitot tube and other experimental instruments, so as to test the dust concentration of the air flow at the inlet and outlet of the dust collector, and to calculate the dust removal efficiency of the dry dust collector, as shown in **Table 4**.

DUST SUPPRESSION

Table 4: Underground Intelligent Dry Dust Collector in the Coal Mine.

Project	1	2	3	4	5	6	7	8	9	10	11	12
Total dust concentration at the inlet mg/m^3	1208.4	1632.8	1332.3	1875.8	1554.6	1088.5	1649.7	1912.2	1482.5	1721.4	2053.3	1821.4
Total dust concentration at the outlet mg/m^3	4.8	5.8	3.4	7.8	5.3	4.2	8.2	9.2	5.1	7.9	8.7	6
Respirattory dust concentration at the inlet mg/m^3	412.9	636.7	426.6	694.0	435.2	315.6	574.9	726.5	587.3	646.5	731.4	821.4
Respirattory dust concentration at the outlet mg/m^3	4.2	5.6	3.0	5.9	4.1	3.6	7.2	7.5	4.5	6.1	7.6	5.2
Total dust removal efficiency %	99.60	99.64	99.74	99.58	99.66	99.61	99.50	99.52	99.65	99.54	99.57	99.67
Respiratory dust removal efficiency %	98.98	99.12	99.29	99.14	99.05	98.86	98.75	98.96	99.23	99.05	98.96	99.36

It can be seen from **Table 4** that in the large-span high-concentration dust test from 1000 mg/m3 to 2000 mg/m3, the dust concentration has basically no effect on the dust removal efficiency of the dry dust collector. Its total dust removal efficiency remains at 99.61% on average, and its dust removal efficiency of respiratory dust is as high as 99.06%, indicating that the filtration accuracy of this dry dust collector is 1-micron level, which can effectively filter respiratory dust.

CONCLUSION

The underground intelligent dry dust collector adopts a new type of production process to develop a dust removal filter material without rolling points. Its flame retardant and anti-static performance is much higher than the requirements of the MT 113 standard. It increases the effective dust removal filter area by more than 20%, and greatly reduces the overall size of the dust collector; the surface of the filter material is coated with PTFE membrane to achieve a filtration accuracy of 0.3μm, and an artificial initial dust cake is established to protect the filter material and to extend its service life; after the high-concentration dust removal test in the range of 1000 mg/m3 to 2000 mg/m3, dust removal efficiency of the dust collector is slightly affected by the value of the dust concentration. Its total dust removal efficiency is more than 99.5% , and its respiratory dust removal efficiency is as high as over 99%. Compared with the wet dust collector, the dust removal efficiency is increased by more than 20%, and is continuously stable, causing no pollution nor waste of water resources.

Underground intelligent dry dust collector in the coal mine can have linkage with heading machine, automatic start and stop, intelligent cleaning, fault detection and alarm, and unmanned operation, and its intelligent control system supplies complete data service, integrating storage, query, report, web publishing functions together, and supports multiple terminal equipment access such as smart phone APP, tablet computers, various computers, so as to provide complete set of dry dust removal technical support for unmanned heading working face. The underground intelligent dry dust collectors are mainly used in the mechanized heading faces. It is limited to the long-pressure short-exhaust ventilation method in the gas environment. The compressed air volume is greater than the extracted air volume. Although the dry dust removal efficiency is as high as over 99.5%, there is still some dust escaping the treatment. Under this premise, it is necessary to adopt effective air flow control methods to control dust, in order to ensure the dust removal effect of the heading face.

ACKNOWLEDGMENTS

This work was financially supported by the Coal Mine Intelligent Dry Dust Collector Equipment Project of Science and Technology Innovation Fund of China Coal Science and Industry Group Co.,Ltd (2018-2-MS021).

Also, the authors would like to thank all colleagues in the manufacturing center of Shenyang Research Institute Co., Ltd. Without them, this research would not have been completed.

REFERENCES

1. Fan L., Wang J.D., Chen L.P., *et al.* (2014) Research and Application of Dry-Type Dust Catcher for Mine. *Environmental Engineering*, **32**: 80-83.
2. Zhang X.L., Shen H.G., Zhou R., *et al.* (2012)Analysis of Impact of the Structural Parameters of Intake Uniform Board on the Airflow Distribution in the Bag Filter. *Environmental Engineering*, **30**: 73.
3. Liu J., Zhang D.Y., Lu Y.P., *et al.* (2016) Se lection Manual of Bag Filter Accessories. Chemical Industry Press, Beijing.
4. Zheng Y.Y., Cai W.L., Wang X., *et al.* (2013) High Temperature Resistant PTFE Membrane Filter Prepared by Adhesive-free Hot-pressing. *Journal of Textile Research*, **34**: 22-26.
5. Li J.(2019) Development and Application of Compactly and Automatic Bag Filter. *Coal Mine Machinery for Coal Mine*, **40**:131-133.
6. Shao X.D.(2015) Realization of Automatic Monitoring and Control in Mine-used Nitrogen Generator. *Safety in Coal Mines*, **46**: 73-75.
7. Wang X.L. (2019) Remote Monitoring Control System for Mine Nitrogen-making Device. *Opencast Mining Technology*, **34**: 43

Coal and the Ukraine crisis

Steelmaker Evraz has abandoned its plan to demerge its metallurgical coal assets due to sanctions on Russia for its military attack on Ukraine.

Due to Western sanctions on Russia, the company said it is 'technically impossible' to implement its demerger plan, which was proposed in 2021 following a comprehensive review and aimed at focusing on its core steel operations.

In a press statement, Evraz said: "In light of the unprecedented sanctions against Russia and Russian special economic measures in response to sanctions, which were outside of control of the company, execution of the transaction became technically impossible and the decision has been taken not to proceed with the demerger."

The UK-listed steelmaker's biggest shareholder is billionaire Roman Abramovich, who is currently facing Western sanctions amid the Russia-Ukraine conflict. Abramovich owns a 28.64% stake in Evraz.

The latest decision comes after the firm indefinitely halted the Russia-based coal assets' demerger plan last month to seek more clarity on sanctions on Abramovich.

These assets are consolidated under PJSC Raspadskaya (RASP).

Evraz considers Abramovich does not have effective control of the company, making the company neither designated nor sanctioned.

EU WILL END RUSSIAN FOSSIL FUEL IMPORTS, STARTING WITH COAL

The European Union's member states have agreed that they will completely end fossil fuel imports from Russia, starting with coal, German Foreign Minister Annalena Baerbock said , without giving concrete dates.

"The answer to these war crimes now with the fifth sanctions package at the European level must be that we as a European Union must completely phase out fossil energy dependence on Russia, starting with coal, then oil, and then gas," she said.

Asked about Ukraine's request for tanks, she added that the EU's members were open to exporting further weapons systems to Ukraine, including systems they had not previously sent. Ukraine says it needs tanks if it is to push Russia out of its territory rather than just defend existing lines of contact.

German Foreign Minister Annalena Baerbock.

IN EUROPE, COAL POISED FOR COMEBACK AMID UKRAINE CRISIS

Coal is heading for a short-term comeback as Europe looks to cut its reliance on Russian gas and oil but the Ukraine crisis could hasten decarbonisation on the longer run, according to energy analysts.

European Union leaders met in Versailles in France to discuss their joint defence policy. They will also agree at the summit to phase out the EU's dependence on imports of Russian gas, oil and coal.

But it is a tough task as the EU sources about 40% of its gas imports and one-third of its oil imports from Russia. It also sources about half of its coal from Russia but oil and gas are the main sources of thermal energy for many European countries. Concerns over energy supplies have prompted calls on the continent to postpone coal phase-outs while quickly ramping up clean power.

Italian Prime Minister Mario Draghi said recently that the country could reopen some coal plants to help bridge its looming energy supply gap and cut its dependence on Russia. The Polish government has also approached Australia for alternative coal supplies. In Germany, where coal-fired power plants were to be phased out by 2038 at the latest, the economic ministers of the 16 German states called for the operations of both coal-fired and nuclear plants to be extended.

German Vice-Chancellor and Economy Minister Robert Habeck said recently that coal plants could run beyond 2030 but the country's ultimate goal was greater energy independence through renewable power.

Michaela Holl, a senior associate at the German think tank Agora Energiewende, said there were discussions in several countries to slow the phase-down of existing coal capacity while ramping up renewables faster.

"This could see greenhouse gas emissions from coal-fired generators decline slower than anticipated … but it would not compromise Europe's climate ambition as the EU Emission Trading System sets an absolute emissions cap on the sector."

Lauri Myllyvirta, a lead analyst at Centre for Research on Energy and Clean Air in Helsinki, said there was a chance that the Ukraine crisis would increase emissions from existing power plants in the next one or two years, but over the rest of this decade, the phase-out of fossil fuel power plants would happen faster than expected.

"The impact of the conflict and the sanctions on fossil fuel markets has been a dramatic increase in prices … However, the increase in the price of fossil gas relative to coal means that power generation is shifting from gas to coal, which increases emissions in the short term," he said.

Gas prices in Europe hit an all-time high in the aftermath of Russia's invasion of Ukraine. Oil and other commodities prices soared as the United States said it was willing to ban Russian oil imports. But Myllyvirta added that Russia's assault had created a new determination in Europe to reduce reliance on fossil fuel imports from Russia in the future, a direction consistent with Europe's decarbonisation goals.

"Germany already announced targets to get to 80% renewable electricity by 2030 and 100% by 2035, which also means a complete phase-out of coal and gas-fired power generation," he said.

Over the past few decades, major European nations have turned to Russia to fill the gap left by retired coal and nuclear plants. The EU aims to reduce carbon dioxide emissions by 55% by 2030 and become carbon neutral by 2050. To achieve its climate targets, it needs to bring down its fossil fuel use and imports.

"Today's crisis raises specific questions about imports from Russia and what policymakers and consumers can do to

lower them," the International Energy Agency said in a report.

The report suggested 10 points to reduce the EU's reliance on Russian natural gas, from supplies, to the electricity system and end-use sectors. The measures include no new gas supply contracts with Russia, replacing Russian supplies with gas from alternative sources and accelerating the deployment of new wind and solar projects.

"Measures implemented this year could bring down gas imports from Russia by over one-third, with additional temporary options to deepen these cuts to well over half while still lowering emissions," it said. If the EU wants to keep its emissions goals, keeping coal power plants running or on standby should only be a very short-term solution, according to Ana Maria Jaller-Makarewicz, a Europe energy analyst with the US-based Institute for Energy Economics and Financial Analysis.

TECK PLANS TO CUT DEBT TO BELOW US$5B AMID COAL RALLY

Teck Resources Ltd. CEO Don Lindsay recently said in an interview that the company plans to reduce its net debt to below US$5 billion amid the recent resurgence of steelmaking coal and zinc prices.

The diversified miner has already reduced its outstanding notes to US$6.1 billion after repurchasing US$1 billion in debt in September and early October.

Driven by a 306% surge in prices for metallurgical coal this year due to Chinese capacity cuts, and a 57% increase in zinc prices thanks to production cuts in the industry, Teck shares have risen more than fivefold this year.

The increase in metallurgical coal prices added another up to US$2 billion in cash per quarter for the company, which made a big difference in achieving the debt reduction plans, Lindsay said.

For each penny increase in zinc prices, the company will make another US$14 million of EBITDA, with Lindsay expecting zinc's price to climb further to hit the "pinch point" through the next six months.

While he was positive on U.S. President-elect Donald Trump talking about infrastructure investments of more than US$500 billion, which will give a major boost to miners, Lindsay sees China as an "overwhelming force" driving the markets.

In addition, the company's Fort Hills oil sands joint venture project can generate significant cash when it comes online in 2017, given the analysts' forecast of US$70 to US$75 per barrel.

Teck reported third-quarter net income of C$234 million, swinging from a net loss of C$2.15 billion a year earlier.

VIETNAM HOPES FOR TECHNOLOGY TRANSFER IN COAL MINING, PROCESSING FROM AUSTRALIA

Viet Nam hopes to establish long-term stable trade and

Minister of Industry and Trade Nguyen Hong Dien.

investment ties with Australia and receive technology in sustainable coal mining and processing from Australia, said Minister of Industry and Trade Nguyen Hong Dien.

The minister made the suggestion during an online working session with Tania Constable, Chief Executive Officer at Minerals Council of Australia, and leading coal and mineral exporters of Australia.

He also noted that the Governments of the two countries have agreed to set up dialogue mechanisms at the ministerial level on trade, energy and minerals.

Regarding coal, Minister Dien said Viet Nam wants to import 18-25 million tonnes of coal for electricity and fertiliser production in 2022. He asked Australian coal exporters, especially members of the Minerals Council of Australia to increase the supply for Viet Nam in April.

According to Dien, Viet Nam's coal import needs account for less than 5% of Australia's total coal export. Therefore, he believed that Australian exporters are capable of supplying coal of suitable quality for Viet Nam's electricity generation.

The minister also asked the Minerals Council of Australia, the Australian Embassy in Viet Nam and ministries of Australia to continue coordinating with his ministry to more effectively support efforts to connect and build long-term partnerships of leading enterprises in coal and minerals of the two countries.

The CEO of Minerals Council of Australia said Australia is fully capable of supplying coal and minerals for Viet Nam. She affirmed that the council will work closely with the Vietnamese ministry to bolster cooperation between their enterprises in coal supply and technology transfer in coal and mineral mining.

At the session, the two sides also discussed in detail the demand and regulations on coal and mineral export and import. Leading Australian exporters such as BHP, Glencore, Yancoal, Whitehaven Coal, Jellinbah Group engaged in talks with four leading Vietnamese coal importers – Vinacomin, PetroVietnam, Electricity of Viet Nam and Dong Bac Corporation – on possibilities of co-operation.

BERLIN WARNS OF DIRE CONSEQUENCES OF RUSSIAN GAS AND COAL SHORTAGE

Head of the Federal Agency for German Energy Networks, Klaus Muller, has warned that the acute gas shortage caused by the events in Ukraine will have serious consequences for the German population.

"Unfortunately, it cannot be excluded that we will have to make decisions that will have dire consequences for businesses, jobs and supply chains in entire regions," RT website quoted Muller as saying.

In the sane context, a report issued by the German Economy Ministry warned that Germany will have to stop operating some of its power plants if it ends coal imports from Russia.

"An immediate ban on coal imports from Russia will lead to a coal shortage after a few weeks," the ministry said in its report.

MAKING A COMEBACK

The energy crisis and Putin's closing of the gas taps are leading to governments and economists to take a second look at coal, once nearly universally condemned as "dirty," as at least a partial solution to the ongoing energy crisis. The Czech government has in fact already gone down this path, leaving environmental and climate activists a little confused about this decision.

In 2022, coal mining at the Stonava mine at OKD, the dominant mining company in the Czech Republic, was due to come to an end. The operation, however, will now be extended until the middle of next year.

At a strange time when climate activists are pushing for wind and solar power plants, and many experts hope for a new nuclear bloc in about 15 years, is the government's decision quite bold? I emphasize government because OKD actually belongs to the state. The Czech finance ministry is in charge of possible further intensive coal mining and wants to know if it would be possible to mine until 2025.

The reason for the extension to the Stonava coal mine is to defend against the energy crisis, reduce dependence on

Russia, and ensure the state's energy security, but another important reason is due to the high prices of hard coal on the world market, which means that even capital-intensive mining in the Karviná basin — one of the important mining regions in the Czech Republic — can now pay off.

Strangely, the decision of OKD and the government did not attract much attention of environmental activists. There were no statements, no demonstrations, not even a protest occupation of the mines. However, as soon as there is talk of extending brown coal mining, it is a different story. At the Christian Democrats congress, the Environment Minister Anna Hubáčková mentioned a debate about this issue among politicians.

"We have been destroying the environment for decades, destroying the landscape for decades, and warming our landscape by burning fossil fuels. If we want to live in a healthy environment, we cannot return to coal," the minister said.

The Fridays for Future movement then immediately called for a strike and demonstration at the Office of the Government.

"We need to free ourselves from our dependence on fossil fuels and start reducing greenhouse gas emissions," the students wrote on social networks. "Russia's aggression has exacerbated this need, and if we are to survive, we must get rid of Russian gas, oil, and coal as soon as possible. We need to accelerate the development of renewable energy sources and fully start using energy-saving technologies," they added.

Are the activists so frightened by the war and energy prices? They probably aren't. Their proposals for resolving the energy crisis are as naive as ever, and their solution only will lead to the deepening of the energy crisis.

Greenpeace Czech spokesman Lukáš Hrábek recently recommended replacing "old" gas technologies with "new" ones. Jitka Martínková from the Climate Coalition described the energy purchase from Russia as "sending dirty money for gas."

But what about coal? The mines in the Most region (another crucial mining region in Czechia) were last occupied by activists last year when the crisis did not exist, and activists aren't responsible for the crisis, are they? Nevertheless, the fight continues. It is conducted against the Počerady and Chvaletice coal-fired power plants (a total of 1,820 MW of the long-awaited adjustable power) and against the exemptions from the mercury emission limit set by the European Commission, which they received from the environment ministry in 2021 for six years. The fight began before the energy crisis, but it did not change its nature.

The set limits have nothing to do with the environment and human health protection. They are based on globally collected values, where American coal contains less mercury than European, which was already disadvantaged from the beginning. Mercury emissions have been so small in the recent past that they cannot be measured. Nevertheless, it later turned out that mercury can be captured on fabric filters used to capture dust, and at the cost of several billion korunas, these filters can be installed in power plants. However, with the planned shutdown of power plants in about 10 to 15 years, this is a non-returnable investment.

European legislation requires the retrofitting of power plants according to best practice, not according to the impact on human health. However, it is aware that operators are aiming for a moving target. The legislation stipulates that if the cost of reducing emissions exceeds the results achieved, the exemption should be granted automatically. In addition, the plaintiffs rely on year-round values of mercury emissions, which are based on tonnes. If one sees these mercury values written out on paper, they look lethal, but such emissions are negligible and harmless once they disperse. It is all very misleading.

According to Greenpeace, such power plants “kill” several dozen people a year. Some coal-fired power plants are also operated by ČEZ, which is partially owned by the Czech government. According to the Duha movement, these power plants have emission limits as well. Activists have not used the word “coal baron” for a long time. However, the suspicion that their fight against coal is more about social class than environment cannot be ruled out. The state is not a coal baron itself.

In any case: once the government’s decision to continue coal mining in the Karviná region has been made, the same arguments could be used for a possible extension of the mining and operation of lignite-fired power plants. That does not mean a “return” to this form of energy, just a defence against current inflation and future threats until renewables, hydrogen and other environmentally-friendly technologies and renewables are actually usable instead of just fantasy.

AUSTRALIA’S CORONADO FLAGS HIGH DEMAND FROM EUROPE AHEAD OF RUSSIA BAN

European and Asian coal importers are expected to join the scramble for alternative sources of the fuel as the EU sanction on Russia looms, analysts and company officials said earlier this month.

Coronado said it expects met coal demand to remain positive in 2022, though improved supply from Australia and Mongolia should balance the market.

It noted, however, that Covid-19 lockdowns in China have disrupted logistics along the steel value chain and hit steel and met coal demand in the short term.

Fellow Australian producers Whitehaven Coal and New Hope Corp had said earlier that they were also approached by prospective customers but that their priority was to serve existing customers.

Coal prices have surged amid the conflict in Ukraine, and while they are lower than their highs in mid-March, Coronado expects them to remain supported by strong demand as well as trade constraints with respect to China and Russia.

“Despite the ongoing uncertainty and tight supply, met coal prices have fallen from their mid-March highs but have remained at levels more than double historical averages,” Coronado said.

The company said its March-quarter revenue rose 22.3% from the December quarter to a record $947 million.

Continuous miners-matching development rates with longwall retreat rates still lagging?

Over many years great strides have been made in the mechanisation of longwall faces with the introduction of higher horsepower and faster power loaders, together with more robust sophisticated power supports, well able to match the speedier coal winning process.

In the advancing longwall method, which is more common in Europe, development of the block takes place only 30 to 40 metres ahead of the mining of the block, and the two operations proceed together to the boundary hopefully in unison.

Today faster face advances rates put great strain on ripping and packing and this aspect of advancing face operations was and still is in many cases the achilles heel limiting face efficiency and reducing potential face advance rates.

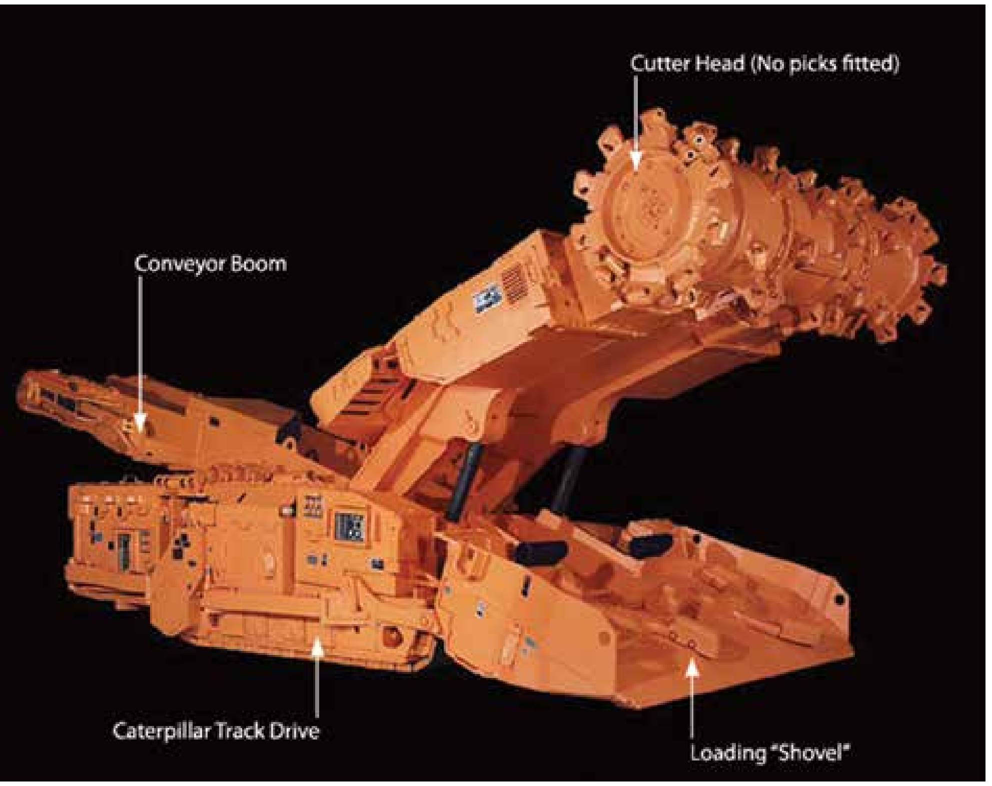
Attempts to mechanise ripping mechanisms such as roadheaders/continuous miners are not difficult, matching this with a mechanised packing process was far from easy and frequently failed. The introduction of monolithic packing went a long way to solving the problem and also improved ventilation.

Many years ago, the traditional road header was at the forefront of all development work associated with advanced longwalls and indeed retreat mining, prior to this was the drilling and blasting process and the manual task of setting the girders in place performed by a team of men known as rippers. This practice is still in place in many operations worldwide.

Nowadays the use of continuous miners fitted with on board bolters or even stand-alone bolters are the flavor of the day. The task of keeping up with todays sophisticated longwall operations in an advancing face is by no means an easy achievement but manufactures developments and innovations.have certainly improved the situation.

CONTINUOUS MINERS

Advancing faces,retreat mining, bord and pillar operations,roof bolting you name it are all the reasons that the continuous miner market is very attractive to a host of



mining equipment manufactures.Matching the productivity gains of continuous mining machines with the increasing performance levels achieved by longwall units has required creative thinking to assure that development is completed in time for uninterrupted longwall production.

Although there are many variations in design, continuous miners mostly consist of five main elements:

- A central body to carry all other components mounted on some type of drive mechanism to provide mobility (most commonly caterpillar tracks).
- A "cutting head" usually rotating drum(s) and/or chains with cutting picks attached
- A loading mechanism to pick up cut coal and deliver it into the central part of the machine
- A conveying system, usually a chain conveyor running in a steel trough from front to rear of the miner
- A rear jib section capable of a degree of vertical and horizontal movement to enable the coal to be delivered into a transport or loaded at a desired point.

Some continuous miners (at one time almost all) could not cut the full roadway width in one pass but had to be moved backwards and forwards and from side to side to cut the full profile. This often results in a very rough rib line (bad for stability and ventilation flow) and delays the ability to install support into/under freshly exposed roof for a period. The advantages of the ability to cut the full profile in one pass was recognized early but was not easy to achieve. Cutting forward in a straight line could be readily accommodated, but it is necessary to be able to turn corners, mostly at right angles, and to be able to retreat the cutting machine from one roadway to relocate at frequent intervals. These factors have proved major stumbling blocks to many developments. In machines which covered the full face, steering in the vertical plane could also be a major difficulty.

The term "continuous" as applied to development machines has been one of the biggest misnomers used for mining equipment because, on development, they are usually anything but continuously cutting. The main delays mostly occur while roof support is installed and often waiting for shuttle cars to return from their discharge point for reloading. When cutting, cutting rates are usually more than adequate, but when averaged over a shift cutting rates are often poor and this is one of the reasons many mines have difficulty developing at rates adequate to prevent long delays on longwall production. As a result, development is an area receiving major attention in recent times. Many of the difficulties have been overcome and most modern continuous miners are "full face" machines. They also have roof bolting equipment mounted on the miner in locations allowing roof bolts to be installed reasonably close to the face.

The "ideal" continuous miner would:

- Be able to cut the full face in one pass
- Be easily moveable between locations without dismantling parts
- Be able to excavate right angle turns with a minimum radius
- Have roof and rib bolters fixed to the machine in a location where each row of the designed support pattern can be installed without moving the miner and be installed close to the cut face if necessary
- Have adequate space alongside to allow good ventilation of the face area for efficient removal of gas and dust.
- Allow strata supports to be safely installed while coal cutting continues.

Many of these ideals have been achieved to varying degrees of satisfaction (the last being an area of minimal success in some cases), but matching development rates with longwall retreat rates is still a major problem for many mines. Increasing numbers of development units to attain longwall continuity is expensive and provides extra strain on all other service functions (personnel, ventilation, materials handling, power and water supplies, gas drainage, etc., etc. and is not usually a satisfactory solution.