THE MINING GEOLOGICAL & METALLURGICAL INSTITUTE OF INDIA

1906

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TRANSACTIONS

ISSN 0371-9538 ● Vol. 117, April 2020-March 2021

A Technical Publication of

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EDITORIAL BOARD

TRANSACTIONS of
THE MINING, GEOLOGICAL AND METALLURGICAL INSTITUTE OF INDIA
Inauguarated 1906 – incorporated 1909 – as the Mining and Geological Institute of India
the word Metallurgical was included in the title in 1937.

Price
- Free to Members
  (Rs. 100/- for each additional copy)
- Non-Members
  Rs. 300/- per copy
- Foreign US$ 15.00 per copy

Pulished by
Ranajit Talapatra
Honorary Secretary
The Mining, Geological and Metallurgical Institute of India
GN-38/4, Sector-I, Salt Lake City, Kolkata-700 091

Printed by
Lalchand Roy & Co. Pvt. Ltd.
Kolkata

CONTENTS

Presidential Address

for 114th Annual General Meeting at The MGMI Building on 27th December 2020

Shri A. K. JHA*

I extend a warm welcome to all present here at the 114th Annual General Meeting of MGMI, a premier institution having a history of more than a century and convey my thanks to you all for showing confidence in me by electing President for the second term.

The strength of MGMI is its available technical knowledge bank which needs to be more contributing factor for sustainability to the energy sector of the country as there is no substitute of fossil fuel in our country at least for the next 5 decades. Even these being the fact, the mineral sector in general and the coal sector in particular are not getting its due recognition, rather always being criticized for its negative impact like.

- Land degradation
- Environmental degradation
- Displacement etc.

But the constraints with which the sector is growing and the effort being put by each and every individual of this sector to overcome the same needs to be highlighted by this institute. When we talk about the sustainability we should look into it in totality.

Without the contribution of coal sector, sustainability in the energy sector of the country is always in question. Now, if this sector does not take pain even after being criticized and do not take measures for sustainability, the energy sector will not be sustainable for next 5 decades. All of us present here should understand this aspect and advocate for the same.

The points raised by Shri T K Lahiry, Past President, MGMI in his address during the 106th AGM of this institute are constraints for the sectoral growth of mining like:

1. Environmental clearance
2. Land acquisition
3. Ecological restoration
4. Transfer of global technology,

which needs to be addressed by expert team of MGMI. I am sure that all of us have tried out

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Presidential Address delivered on 27th December 2020 at the 114th Annual General Meeting at MGMI HQs Building, Salt Lake, Kolkata.

*President, MGMI and Former Chairman, Coal India Limited

level best but we could not reach to the desired level in short span of one year time.

Energy sustainability of the country is directly dependent on sustainability of this sector so is the sustainability of society and political stability of the country. We need to advocate this in all the forum/platform. We should further advocate the best use of land by extracting mineral upto 1200 meter depth instead of 200 to 300 meter i.e. the present depth of workings.

The exploration of our coal reserve is upto 1200 meter depth and our average mining depth currently is less than 300 meter. This is an area where introspection is urgently required. If available land mass is used upto greater depth as being done in countries abroad, we can ensure arability of fossil fuel for energy security of the country without any much requirement of land. The emphasis should be on vertical expansion rather than horizontal expansion.

Extraction of mineral should be planned beyond 300 meter and upto 1200 meter depth which will solve the land requirement constraint. The EC/FC issues will also be resolved. Coal blocks should be allocated keeping in mind the vertical expansion concept. But for this we require to transfer the available state-of-the-art global technology for the extraction of minerals at higher depth. This will address sustainability of Energy sector. The mining sector will have less negative impact on environment and land degradation and will ultimately bring social stability.

We are always blamed for degradation of the ecology and environment. A model is already available in coal companies where ecological restoration is being done under the technical guidance of FRI, Dehradun as well as Delhi University and has emerged as a very successful model. If it is practiced in a very big way after extraction of minerals we can create natural forest and NO GO area. This will rehabilitate the displaced forest dwellers.

Now, let me address the organizational and structural part of MGMI. The MGMI will grow lips and bound, the concept of a 4 Vice Presidents was introduced. But the result does not seem to be much encouraging since the activities in the interest of MGMI has not grown to the desired level under the various spheres of the Vice Presidents, may be because of their pre-occupation. It is expected that the Vice Presidents and their team will rise to the occasion and put in more efforts to contribute towards the Mission and Vision of MGMI.

So far, our contribution has been limited to starting programme for PAPs as well as SC/ST candidates under CIL command area on nomination basis and submission of a report to MoC titled – Individual Evaluation and assessment of major Central Sector Schemes/ detailed drilling schemes of MoC. I take this opportunity to congratulate the then Committee Members and their team for the efforts made for finalizing the training programmes with CIL on nomination basis.

On the infrastructural front, a lot of work has been taken up during the last few years.

It is matter of pride that the quality and contents of the MGMI News journal is being appreciated by the readers. I congratulate the Editorial Board of MGMI at the same time wish that more and more efforts are made to further improve and enrich the contents of the News Journal for the benefit of the readers and the members. Further, I am of the view that the observations made by the critics, if any should also find a place in the journal which ultimately will be a guiding path for improvement.

THANKING YOU,

From Editor's Desk

Dr. Khanindra Pathak*

The Mining Geological and Metallurgical Institute of India (MGMI), the oldest institutions of its kind in Asia, founded in 1906 is continuing its sincere efforts of providing a platform for scientific and technological interactions of the academics, researchers and industrial practitioners. Indian mining and metallurgical industry have remained vibrant for more than 100 years now. The Earth scientists from all over the country along with global experts are making continuous and significant contributions towards the discovery and delineation of many mineral deposits.

With the advancements in science and technology, a new dynamism in the mineral and mining sector is growing at an unprecedented rate. Thanks to the initiative of the Government of India that exploration for minerals is now in the top of priority list for industrial growth and development. Companies like NMDC are developing technology driven project for rapid exploration. Reconnaissance survey to exploration to exploitation, at each step high speed processing and validation of the results make the project management easy. Using the emerging drone technology and advanced remote sensing techniques like hyper spectral data acquisition are becoming essential for mineral exploration projects. Such Data driven decision making in mineral industry has wide range of future possibilities.

From tangible and intangible asset management and safety and productivity management to mine closure and post mining mine site restoration, all sectors of planning and execution of mining and mineral industry will have to necessarily embrace artificial intelligence embedded applications. Now the computer professionals and mining companies have a long history of working together on problems of the mineral industry. The new technologies of artificial intelligence and machine learning have altered the fundamental way of data collection, its processing and retrieval; all critical for decision making by the management. The interdisciplinary approach of solving a problem is leading us to a future where more and more diverse knowledge streams would be integrated, in order to reach the finality of solution. To this end, institutions like MGMI will be playing a major role in interdisciplinary knowledge dissemination and innovative ideas generation.

*Department of Mining Engineering, IIT Khargapur

Sustaining the high growth rate of Indian economy depends largely on the pace of growth in mining of coal and other minerals. There has been persistent decline in underground coal production over the years with more emphasis on open cast mining, which has developed as an area of core competence of Coal India Limited and other companies. The quantum jump in opencast mining activities has brought the environmental impact of mining under scanner. Large scale opencast mining always induces systemic and chaotic transformation of the socio-economic foundation of a society in the vicinity. Large scale mechanisation and introduction of mega equipment in mining disrupt the prevailing economic activities and may induce new societal and technological challenges. Environmental and occupational health hazard potential increases with the volume of materials to be handled. The expectations of the society and local population also change. The mine accidents are not accepted and tolerated any more. Therefore, social sustainability, safety and health issues such as employment, cash benefits, training for self-employment, reduction of accidents and expectations safety and health are the ultimate choice of mining companies today. The MGMI invites the authors to contribute in these areas in order to deliver path setting goals to all concerned.

For the ease of doing business in coal mining, an unified controlling authority eliminating present systems of multiple permitting and approval routes is now being seriously thought. However, without certain degree of digitisation and scientifically modelled operation control and transparency of decision making, such unified control of coal mining may not be meeting its goal. MGMI will have to facilitate deliberations on logical framework for such administrative transformation in the coal mining sector.

Traditionally, mineral economics and trading in India has not been popular amongst the students of earth sciences and engineering. There is only a limited research work in these fields. Dedicated workshops, seminars and deliberations on mineral economics and business are also limited. The economics related to mine closure management is also not widely studied. Keeping the essential considerations of the mine closure, it should be the goal of mining companies to integrate the closure plan with the mining plan in a cohesive manner. The practical estimates applicable during the mine closure exercised by different parties can find interesting readership among the researchers and practicing engineers. These aspects of mining are much more relevant to the practical operations of mine life cycle. We hope to find new authors contributing in these areas in our forthcoming issues that would benefit our readers.

The last year of the unprecedented pandemic did affect all spheres of life including academic, industrial, personal, as well as professional. Each one of us suffered from loss, agony and pain. MGMI also faced challenges during this period. The transactions of the MGMI suffered from setbacks and also delayed publication of Vol. 17 (April 2020- March 2021) due to the pandemic. As we march towards a better tomorrow, we cannot be oblivious to the lessons learnt during difficult times. We have now brought in certain flexibility in the processing of the publishable contributions from interested authors.

We hope with the invaluable cooperation of our members and readers the new editorial body under leadership of Dr. A K Singh will take the publication wing of MGMI to new heights.

TECHNICAL ARTICLES

EXPERIMENT AND DEMONSTRATION OF RAPID FOREST REGENERATION OVER STEEL SLAG

Anjani Kumar S V Brahmandam[a*], Khanindra Pathak[b],
Saroj Kumar Banerjee[c], Padmanav Mahakud[c]

Abstract

As mining has become an indispensable part of a country's development, the need of managing the waste that is generated through this has grown. Steel slag is one such wastes that is being generated in huge quantities and is proving to be a menace for environmental sustainability. This paper provides an overview of different processes through which steel slags are generated and their composition. It also touches upon various alternative uses of steel slag that are being employed today and the associated drawbacks. Although it was found out that the current use of steel slag for construction purpose solves the problem of its overaccumulation to an extent, its inherent physical and chemical properties are bound to reveal its negative impacts in long run. In this context, the present study investigated the reclamation of steel-slag affected site using bioremediation techniques. Bioremediation is shown as an effective solution in combination with modified Miyawaki method. Efficacy of Panchagavya-an organic nutrient rich solution, mulching and Vetiver grass boundary has been demonstrated. Phenotypic observations made for over a period of one year on twenty-two selected species has been discussed and the best performing plant species was identified. Species belonging to the family Fabaceae out-performed others and have shown encouraging growth during the experimental period over the steel slag. This paper clearly depicts the significant impacts of meteorological factors like temperature, evapotranspiration, precipitation and soil moisture on plant growth patterns.

Keywords : Steel slag, Bioremediation, Modified Miyawaki method, Panchagavya, Meteorological factors.

1. Introduction

Steel slag is a by-product obtained during the manufacture of steel and is produced in the course of separation of molten steel from the impurities. These slags vary in their composition based on the process followed for generation of steel. Accordingly, they are called Basic-Oxygen-Furnace slag (BOF slag), Electric-Arc-Furnace slag (EAF Slag) and Ladle slag. The composition of these slags vary due to different types of fluxing agents that are used in the process. Process of production and the composition of different kinds of steel slag can be described as follow :

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1.1. Basic-Oxygen-Furnace Slag (BOF-S)

BOF slag is named after the furnace from which it is produced-Basic-Oxygen-Furnace (BOF). This is also called as LD slag (after the process used: Linz-Donawitz). The main raw material charged into BOF is molten Iron (80-90%) that is obtained from the Blast Furnace (BF). This, along with steel scrap (10-20%) form the key raw materials of BOF[1]. Steel scraps play an important role here in maintenance of temperature (1600-1650˚C). The most interesting feature of BOF is that it is self-sufficient in energy. The impurities present in the pig Iron get oxidized upon supply of oxygen (over 99% pure) through the ladle and these oxidation reactions produce enough heat for the Iron to melt. No additional fuel is required. While most of the impurities can be removed by oxidation, few elements like Sulphur need to be reduced and hence requires a different process for their removal[2]. The oxidation reactions occurring in the BOF are represented through equations [1] to [6].

$\frac{1}{2}\ \{O_2\} = [O]$ [1]

$Fe(l) + \frac{1}{2}\ O_2\ (g) = FeO$ [2]

$[Si] + \{O_2\} = (SiO_2)$ [3]

$[Mn] + \frac{1}{2}\ \{O_2\} = (MnO)$ [4]

$[C] + \frac{1}{2}\ \{O_2\} = \{CO\}$ [5]

$2[P] + \{O2\} = (P_2O_5)$ [6]

([] - solution in steel, () - in slag & {} - in gas)

All these oxidation reactions lead to high temperatures and henceforth charging of steel scraps lead to considerable amount of cooling of the system as each kilogram of steel scrap consumes 340 kilocalories of energy. Fluxing agents like Lime (CaO), Dolomite ($CaCO_3.MgCO_3$) are charged into the furnace to remove unwanted elements from the melt[3]. These oxidation products react with these fluxing agents to form slag. Hence, composition of the hot melt received from the BF (Blast Furnace), amount of steel scrap charged into the BOF and the concentration and nature of fluxes used in the process very much determine the characteristics of BOF-S[4]. The liquid steel thus obtained forms an immiscible layer with the slag floating on the tap. The liquid steel is first tapped into the ladles and then the slag is poured into a slag pot. Both are subsequently sent to further refinements based on the requirement.

1.2. Electric-Arc-Furnace Slag (EAF-S)

EAF-Slag is generated from EAF, which uses steel scrap as its primary input. EAFs convert steel scraps into high quality steel and use high voltage electric arcs instead of gaseous fuels to melt steel. The resistance offered by the steel scrap produces enough heat for it to melt[5]. Lately, preheated steel scrap is being used to reduce energy consumption by 90 kWh/t-steel- a twenty percent reduction in the electrical input energy[6]. The process starts with charging of steel scraps into the EAF and then electrodes are slowly lowered into the furnace. As high voltage electricity passes through these electrodes, an electric arc is formed with the steel which results in the melting of the steel. Oxygen and Carbon are infused into the furnace to improve foaming and also to aid the bath chemistry. Foaming reduces the radiation effect on the furnace lining and also enhance the energy transfer in the system[5]. Fluxes like Lime or Dolomite are charged into the EAF. The oxidation products of impurities (Silicon, Aluminium, Manganese, Phosphorous, Carbon) present in the steel scrap combine with the flux to form EAF-S. As slag floats on the liquid metal, the liquid steel is tapped into ladle and the slag is poured into slag pot and can be sent for further refinement. The reactions that occur in EAF are very much similar to those occurring in the BOF.

1.3. Ladle-Furnace Slag (LF-S) :

Ladle Furnace is used in secondary steel making operations, meaning which, is used as a refinement furnace for the steel coming from BOF and EAF. Ladle furnace is used for the production of high-grade steels of desired composition. Henceforth, it is also known as refining slag[7]. Refining process may include desulfurization, degassing (of Oxygen, Nitrogen and Hydrogen), decarburization and removal of impurities[1]. The processes in the order in which they occur in LF are: charging with steel, deoxidation, alloying, removing of impurities, homogenizing, desulphurization, Temperature management and casting[8]. Equations [1] to [12] depict the oxidation reactions that occur in LF.

$2[Fe] + 3[O] = [Fe_2O_3]$ [1]

$[Fe] + [O] = [FeO]$ [2]

$[C] + [O] = CO_{(g)}$ [3]

$[Si] + 2[O] = [SiO_2]$ [4]

$[Mn] + [O] = [MnO]$ [5]

$2[P] + 5[O] = [P_2O_5]$ [6]

$2[Cr] + 3[O] = [Cr_2O_3]$ [7]

$(CaO) + [S] = (CaS) + [O]$ [8]

$(CaCO_3) = (CaO) + CO_{2(g)}$ [9]

$2[Al] + 3[O] = [Al_2O_3]$ [10]

$[Ca] + [O] = (CaO)$ [11]

$2[B] + 3[O] = [B_2O_3]$ [12]

([] Solid, () Liquid, (g) Gas)

Different alloys are added to LF to produce different grades and kinds of steel. Henceforth, LF-S has varied composition based on the end product desired.

1.4. Composition of BOF-S, EAF-S and LF-S

As the primary inputs, type and quantity of flux added change from furnace to furnace, the composition of slags generated from the respective furnaces also differ in their composition and properties. Table 1 gives the minimum and maximum average values recorded for various components of slag across the world.

Table 1 : Chemical composition of different Steel slags

Elemental composition (%)	Steel slags		
	BOF-S	EAF-S	LF-S
CaO	30-60	23.9-60	30-60
SiO_2	7.8-15.2	9-20.5	2-35.2
MgO	4.1-15	2.9-15	1-11.9
FeO	7-26.3	5.6-34.4	0.44-15
Fe_2O_3	9.81-38.06	20.3	0.22-3.3
SO_3	0.1-0.2	01-0.2	0.1-0.8
MnO	1.9-4.2	3-5.6	0.4-5.0
TiO_2	0.4-0.9	0.56	0.3-0.9
P_2O_5	0.2-1.5	0.3-1.2	0.01-0.4
References	9, 10, 11, 12	9, 13, 14, 15	9, 7, 16

Based on their chemical and physical properties, these slags are employed in various fields for numerous purposes. While usage of steel slag has positive impact on many industries economically, environmentally it has multitude of negative effects which are grabbing the attention of the researchers of late. Various uses of the steel slag and their associated drawbacks are shown in table 2.

1.5. Usage of steel slag

Physical and chemical properties of slag enable them to be used for various purposes ranging from construction of roads to being used a material for carbon sequestration. But, each of them have their fair share of drawbacks. Table 2 shows in brief, the drawbacks associated with different kinds of applications of steel slag.

Table 2: Conventional utilization of steel slag and its associated drawbacks

Sl. No.	Purpose	Drawbacks	References
1	Construction of roads	• Produces leachate in due courseof time • Swelling properties lead to structural instability.	3, 17

Sl. No.	Purpose	Drawbacks	References
2	In Cement industry	• Presence of Iron Oxides has adverse effect on cement quality • Swelling properties leads to structural instability.	3, 18
3	As Fertilizer	• Can be used mostly in acidic soils only • Quantity of steel slag that can be consumed for this purpose is very low. • Transportation costs. • Possibility of leaching • Possibility of air pollution	3, 19, 20
4	For stabilizing soils and contaminant immobilization	• Potential of getting into food chain • Huge transportation costs • Risk of over-liming of soils • Potential air contamination through dust	3, 21, 22
5	For recovery of different metals	• Requires further refining of slag in many cases. • Huge quantities of waste is again generated after recovery. • High on investment.	3, 23, 24
6	Waste-water treatment	• Quantity of steel slag used for this purpose is very less. • Highly dependent on retention rates. • Displacement	3, 17, 25
7	In Carbon sequestration	• The amount of Carbon sequestration taking place is highly unpredictable. • Most of the steel slag remains unused to tap for other purposes in order to sequester carbon. • Doesn't reduce its potential of causing threat to biota.	3, 26, 27

Looking at the drawbacks associated with each process, it was concluded that bioremediation of steel slag would be beneficial both in terms of economics and also environment. Henceforth, a rapid forest generation over steel slag was worked out and demonstrated in TATA Steel-BSL (TSBSL), Angul. While the commercial utilization of steel slag are of a priority in any steel plant, the utilization of some old stocks may not be always possible to effectively commercialize and in-situ utilization by some innovative ways are often encouraged. The land covered by spillage from stock piles often create environmental nuisance to the neighbouring communities while the land also gets degraded. That is why, in the present investigation, attempts were made to bioremediate the steel slag covered land around the steel slag stock-piles to create a phytographic barrier. The following sections bring out the results of our findings.

2. Background study of TSBSL

According to the Greenpeace International (an NGO spread across 55 countries) Angul-Talcher corridor is one of the world's worst Nitrogen Dioxide (NO_2) emission hotspots **(Fig. 1)**. This is because of the coal fired power plants and industrial clusters.

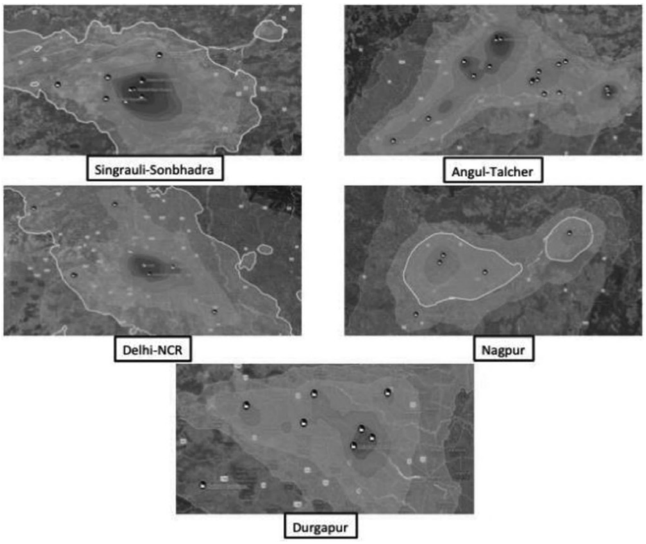

Fig. 1. NO_2 emission hotspots of India
(source: Greenpeace International report, 2019[28])

TATA STEEL-BSL is at the heart of this Angul-Talcher corridor and is also near to other huge industries like NALCO, LANCO, etc. This plant has been operational since the year 2004 and in these 16 years since its inception, it has produced thousands of tonnes of steel. This has resulted in the generation of thousands of tonnes of steel slag. As the steel slag deposits have begun to grow into huge mounds, possibility of these getting carried away by wind onto the adjacent habitations and fields also grew **(Fig.2)**. This erosion is highly undesirable and leads to long-term problems and contamination of the surrounding areas. Henceforth, the need to contain and use this steel slag has increased.

Fig.2. Heaps of steel slag in TSBSL
(Source: Google Maps)

These slag mounds are unsupportive for the plant growth as such, but they can be remediated and used for plant growth with the help of few amendments. Henceforth, identifying the nature and kinds of amendments that are required to make this slag supportive to plant growth would be a challenge, as devoid of nutrients, plants growth will not take place.

As all species cannot adopt themselves to this environment, identifying few best native species would be the next challenge. Plants which can suit themselves to this tropical climate of Angul (Avg high temperature of 32.9˚C and Avg low of 21.5˚C and mean total rainfall of 1300mm/year- IMD) and can also withstand the heavy dust cover are to be planted along the boundary wall. Development of green belt along the boundary wall would not only check the erosion, but also adds positively to the aesthetics and the health of the environment as well.

3. Methodology and experimentation

As a part of Green belt development through Miyawaki method, 3000 m^2 area with slag upto a depth of 4-5 meters was selected. A total of 22 native species of plants were identified based on the frequency of their occurrence in the surroundings and were procured from nurseries. Vetiver grass was propagated to help in forming the boundary of the plantation and check the erosion. Vetiver grass also helps in bioremediation in a great way.

To aid and enhance the bioremediation process, the slag is dug and mixed with top soil and cow dung, and other organic amendments were supplied to help in initiating plant growth. Over this, a 30 cm layer of top soil is deposited, mixed with an organically prepared nutrient solution-Panchagavya. It is composed of cow dung, cow's urine, milk, curd, ghee, sugarcane juice, tender coconut water, ripe banana and toddy[29]. This is highly nutrient rich and hence was used to aid in plant growth.

The mound is mulched (mulch is a layer of material like Paddy straw, applied to the soil to check erosion, improve fertility of soil as well as its water retention capacity) using rice straw and the plants were planted at these sites using a modified version of Miyawaki method. Figure 3 explains the steps of Miyawaki method of afforestation in brief.

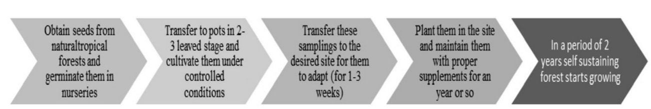

Fig.3. Steps involved in Miyawaki method of afforestation

The plants were periodically administered with 2% solution of panchagavya to foster their growth.

The growth patterns were periodically monitored and the phenotypic details such as plant height and stem diameter were recorded.

The tree height was measured using an *Inverse Direct Tape Drop method* wherein the tape was used and the height was measured starting from the ground level. This is one of the most accurate methods used. Sine method of measurement could not be employed due to high density of plantation.

Tree girth/diameter was measured using *string method* at a uniform height of 10cm from the base level (the level of point of contact between the stem and the top soil on emergence). In this, the string was used to measure the circumference of the stem and then, the length of this string is measured using a tape. DBH (Diameter at Breast Height) method was not used as it is measured at a height of 4.5 feet.

4. Results and Discussion

Phenotypic characteristics exhibited by top five species out of the twenty-two species planted is shown in table 3.

Table 3. Phenotypic characteristics of top five species that performed well at TSBSL

Name of the Plant	Family	02nd August,2019		20th October,2020	
		Avg. Plant Height (Feet)	Avg. Stem Diameter (Cm)	Avg. Plant Height (Feet)	Avg. Stem Diameter (Cm)
Sesbania grandiflora	Fabaceae	7.1	8	17.2	41
Peltophorumpterocarpum	Fabaceae	4.5	4.3	11.5	18.9
Cassia seamea	Fabaceae	5.5	4.8	12.8	17.9
Albizia lebbeck	Fabaceae	4.2	3.9	9.0	13.4
Terminalia catappa	Combretaceae	5.1	5	8.3	17.7

The measurements were recorded over a span of one year and have given conclusive results as to which species adapted well and performed better. The table indicates the average growth of 5 to 10 plants per each species selected. According to this phenotypic data, *Sesbania grandiflora* could be seen outperforming other species by a great margin.

Given below are the images, indicative of the Green-belt development and plant growth over different time periods in a span of 1 year. One can clearly observe Sesbania grandiflora outmatching other species in these images.

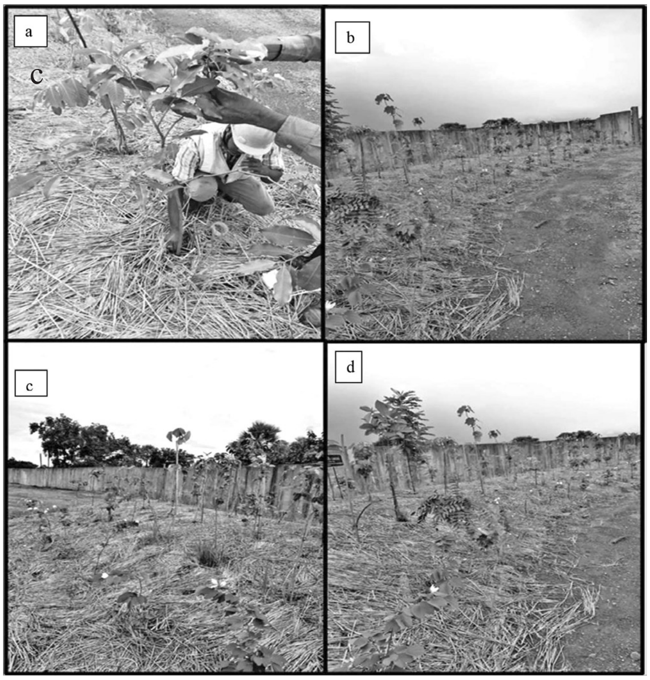

Fig. 4. Plantation along the boundary wall for mini-forest development on 2nd August, 2019

Fig. 4a is indicative of the method used for measuring plant height- Inverse Direct Tape Drop method. Boundary wall along which the Miyawaki plantation has been carried out could be observed in Fig. 4b. Fig. 4c and d depicts the mulching cover done using paddy straw and also the height of the mound created by mixing slag with top soil and other amendments.

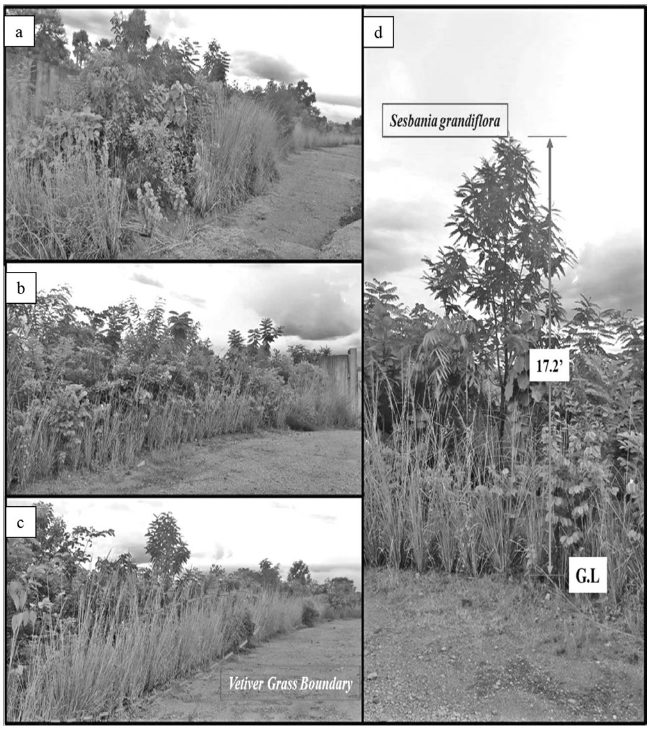

Fig. 5. Status of Mini-forest development as on 20th October-2020

Fig. 5a shows developed green belt over the steel slag in a span of one year. While Sesbaniagrandiflora (Fig. 5d) showed the best growth rate with 17.2 feet, vetiver grass boundary (Fig. 5c) flourished and formed an effective boundary. The growth of all species was very luxuriant due to administering of panchagavya and efficient mulching. In Fig. 5b, it can be observed that the boundary wall is no longer visible.

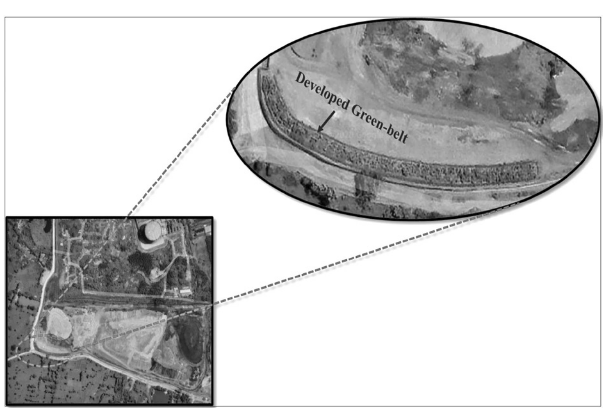

Fig. 6. Developed Green belt along the boundary wall of the experimental site in TATA STEEL-BSL, Angul. While the rest of the area is unsupportive for plant growth and is devoid of plant species, the area developed under Modified Miyawaki method (area in the inset) is flourishing with greenery. *(Source: Google satellite maps)*

Fig.5 and 6 represent the current status of the Green belt wherein one can observe the rest of the slag dump site with absolutely zero vegetation while the plantation developed along the wall has shown excellent growth and tolerance to the harsh conditions. Based on the study one could conclusively decide on the best performing species and also the influence of other factors on these species. The effect of various factors and the reasons for varied growth rates exhibited by the plants are explained below.

4.1 Effect of precipitation on the growth rate

As per USGS, Precipitation is water released from clouds in the form of **rain**, freezing rain, sleet, snow, or hail. Water deprived conditions or over abundant conditions both leads to unavailability of nutrients to the plants. Hence, optimum levels of precipitation in the form of rain is ideal as well as essential for proper plant growth[30]. While the observed cumulative precipitation over the months of August, 2019 to October, 2019 was optimal for plant growth, cumulative precipitation for the months of November, 2019 to March, 2020 was very low sometimes reaching drought like conditions with cumulative monthly rainfall of 1.73 mm (December, 2019). That is the reason why all the plants have grown significantly during the months of August, September & October, 2019 (*Sesbania grandiflora* grew 5.5 feet in 75 days) and plants showed almost a period of no growth during the months of November, 2019 to March, 2020 (*Sesbania grandiflora* grew 2 inches in all these months put together). As the cumulative rainfall increased again in the months of April, 2020 to September, 2020, the growth rate plunged again. The same has been depicted in the graph given below.

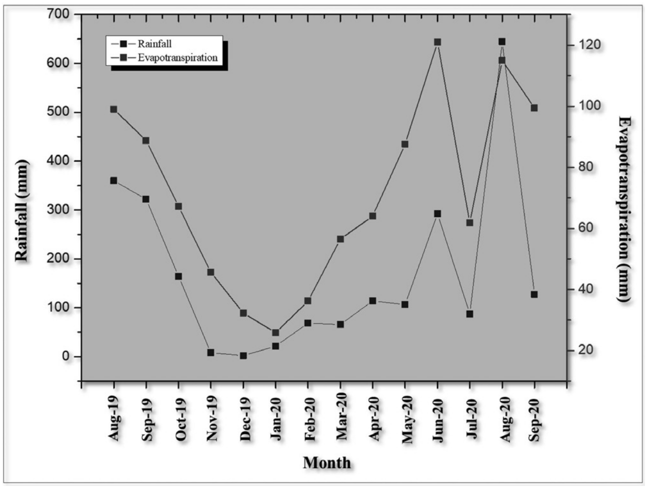

Fig.7. The graph shows the monthly cumulative rainfall (mm) information of Angul from 1st Aug, 2019 to 30th Sept, 2020 using IMD GRID data on one Y-axis while depicting the monthly cumulative evapotranspiration from 1st Aug, 2019 to 30th Sept, 2020 using NRSC VIC Model data on the other Y-axis. *(Source: Ministry of Jal Shakti, GoI)*

⏩ 4.2 Effect of evapotranspiration on plant growth

Evapotranspiration is the sum of transpiration and evaporation put together. Greater the amount of evapotranspiration, higher the amount of stress on the plants. In the months of November, 2019 to March, 2020 evapotranspiration rate has exceeded the precipitation rate (e.g., while cumulative precipitations for the months of November-2019, December-2019 and January-2020 were 8.1mm, 1.73mm and 21.47 mm, cumulative evapotranspiration for the same was 45.6 mm, 32.34 mm and 25.83 mm respectively.) The graphs clearly indicate this and this is the reason for the sudden and drastic decline of growth rate of all plant species during this period. As rainfall increased and exceeded the transpiration rates, the plants growth rate got better and started growing at enhanced growth rates. Mulching played an important role in retaining the soil moisture during the drought-like conditions that arose during the months of Nov, 2019 to Feb, 2020.

⏩ 4.3 Effect of temperature and soil moisture

Too high or too cold temperature conditions are always detrimental to plant growth. As tropical temperature conditions prevail in Angul with an average temperature varying between 15.1˚C to 39.8˚C. They act as ideal conditions for plant growth. Fig.8 shows the temperature variations across months and also the resultant average soil moisture (%) of Angul. Average soil moisture in turn depends on the precipitation, evapotranspiration and temperature of the area. It is the amount of water contained in the soil and is available for absorption by plants. Higher the soil moisture, better the plant growth.

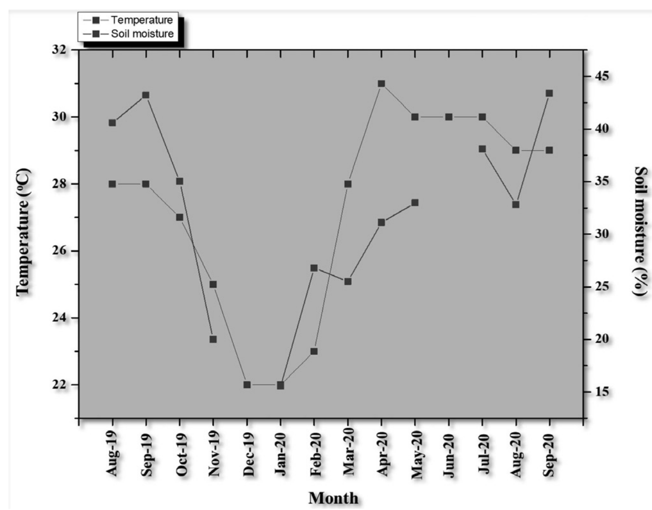

Fig.8. Average monthly temperature readings of Angul from 1st August, 2019 to 30th September, 2020 *(Source: timeanddate.com)* and Average monthly soil moisture (%) of Angul from 1st August, 2019 to 30th September, 2020 *(Source : Ministry of Jal Shakti, GoI)*

All these factors together have resulted in the varied growth patterns seen over time and for the green-belt development along the proposed experimental site.

⏩ 5. Conclusions

The present work is first of its kind in any steel plant.

As it is observed that, steel slag is highly alkaline and did not support plant growth in and around the dump site. Proper mixing of the slag with soil and panchagavya provided the nutrition required for the plant growth initially. As the plants got acclimatized and adapted themselves to these conditions, they began to grow on the steel slag utilizing the nutrients present in the slag. As the plants were carefully chosen based on the Miyawaki principles, they showed better survivability and growth. Based on the experiment carried out, it can be concluded that the usage of panchagavya in combination with Miyawaki principles can be used for rapid forest generation over steel slag. Phenotypic studies of all the selected twenty-two species could be summarized to identify the best performing species. Based on that, it can be clearly stated that *Sesbania grandiflora* (Fabaceae), *Peltophorum pterocarpum* (Fabaceae), *Alstonia scholaris (Apocynaceae)*, *Thespesia populnea* (Malvaceae), *Terminalia catappa* (Combretaceae), *Cassia siamea* (Fabaceae), *Albizia lebbeck* (Fabaceae) *and Pterospermum acerifolium* (Malvaceae) are best performing species for conditions like these. Species belonging to the family- Fabaceae have adopted themselves better and have shown the best growth rates when compared to other species.

The impact of meteorological factors have to be taken into consideration during rapid forest regeneration over unusual substrates like this. High levels of evapotranspiration exceeding the precipitation rates have decreased the growth rates by 96.96 percent (%). Plant's sustenance in such harsh, water scarce conditions can be attributed to mulching. Mulching has effectively retained soil moisture necessary for plants survival. It has also been found that vetiver grass is best suited as boundary plantation. Vetiver checks the nutrient run off from the system during the months of heavy precipitation. The modified Miyawaki method demonstrated in this paper can be implemented throughout tropical climates with similar conditions. Moreover, it can be concluded that steel slag can be easily and effectively utilized through bioremediation thereby reducing its environmental footprint. Besides, this collaborative experiment of TSBSL and IIT-KGP has revealed that this type of bioremediation attempt provides an opportunity to encourage local unskilled people for their livelihood generation as well as to propagate this innovative way of rapid forest regeneration. Thus, this approach also provides a positive social footprint. The success in development of green belt demonstrated in this project establishes that this can be horizontally implemented in other similar industries to comply with the MoEF&CC requirements of 33% green belt norms.

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APPLICATION OF DATA ANALYTICS FOR PERFORMANCE ANALYSIS OF DUMPTRUCKS

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Abstract

Mining Productivity is one of the most important targets that mining companies aspire to achieve with optimal capital and operational investment. Depending on the geo mining conditions and adopted technology, the mines need to tackle number of issues that could be liable to jeopardize the productivity of the mines. Mining operations involve use of huge amount of energy from various sources like electricity, pressurized fluids, momentum of moving objects etc. It should be noted that the production of such energy requires high capital investment. Thus it is essential to plan best possible scenarios for energy production and utilization as well as possible releases. To monitor such movements and energy releases, sensors can be used, which further will lead to data generation. The data generated can be monitored to detect any common patterns or discrepancies in the entire working system. These sensors can be used in all types of machines deployed in the mines. In any surface mine deploying shovel-dumper acts as a primary mining machinery, the fleet of dumper needs to perform their role as planned to maintain safety and productivity of the mine. Therefore, in this study dump trucks are investigated. South Eastern Coalfields of CIL is one of the very important subsidiaries contributing to around 20% of India's total coal production. Dumpers play an important role in maintaining this production level. Thus, it was planned to use data analytics for studying the dumper operations and their relationships with safety and productivity of the mine. The data collected was of fourteen 240 ton dumpers which are currently deployed in the Dipka Project of SECL. The analysis was done to understand the workings of the dumpers and to identify some patterns in their workings. The study revealed that there exist certain patterns in the workings of the dumpers. These patterns/results are still to be confirmed from the concerned competent individuals.

1. Introduction

Maintenance is an integral part of mining engineering. Without managing the challenges of safety, no mine can remain productive. Safety aspects are always in the priority in all modern mines, however, fatalities or serious injuries in the mine workings are not yet fully eliminated. Of course, with modern technology and advances in mine monitoring, it has reduced the number of incidents and accidents in mines. Accidents, as in any other industries, in mining also are either due to carelessness or are caused by technical issues related to mechanization and uses of machineries. The mines do always monitor all potential areas of accidents. With the advent of the applications of ICT and IoT in the mining sector, it is now

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possible to identify the patterns in many of the accident-causing technical faults enhancing the maintenance capability of the mine. Identifying these potential causes can lead to the prediction of failures for a set of given conditions and scenarios (Singh et. al, 2018). Shortening of the gestation period of the capital is always necessary, particularly for a project of high capital investment. For this, productivity plays a major role. It is true that with the introduction of new efficient machineries after the industrial revolution 3.0, the productivity grew at a faster rate than ever before. Mining machinery today is completely different from that of the late 19th century. However, with the beginning of the industrial revolution 5.0, we can assume that there will be a major disruption in the present way of working and new normal will be emerging. Thus, it is essential that modern machines uses data collection and information generation. Such information, when analyzed will result in further details of the necessary scope of improvement and based on those models can be generated for the best possible outcomes. Since this area is still evolving, hence, there has not been a huge amount of work done in it. And of the work done, there are a lot of speculations that are made of where the things can be made more vivid. However, recently in the past decade with the advancements in analytical tools, visualization interfaces and machine learning, a lot of focus is on this particular issue of how to address the safety and productivity through some of the newest technological researches. From India's perspective, many of the mines are being digitalized in different ways and machineries and technologies are imported. However, when it comes to indigenous systems or models, we are well below par as compared to the Western countries. There exists a crisis of competent manpower amongst the existing employees in the mines to manage advanced technology (Kulshreshtha and Parikh, 2002). The present generation's graduates have the required skills and they are looking forward to adoption of data driven management in mining sector so that they can play a important role in analyzing the sensor acquired data for smart management decisions. It is now possible to acquire data for accessing through cloud and analyze them to communicate critical findings. However, for the analysis of all these data, sensors play a very crucial role. 'Automation', 'Machine Learning', 'Internet of Things', 'Robotics', 'Big Data and Real Time Data' are now being widely discussed and there is a new horizon for their applications in the mining field.

The present paper discusses the analysis of available operational data of high capacity off highway trucks in a surface coal mine to reveal its productivity and safety status. For this purpose, the data regarding the operations and breakdown were acquired and analyzed using available visualization tool Tableau. The results of this analysis are discussed in this paper.

2. Case Study

The mine under study was producing 20Mte per year and with introduction of high capacity shovel and dumper it is going to produce 25Mte per year. The total lease area covers an area of 2000.642 Ha. The geological block is 12.42 sq. km (Only acquirable block). The deposit has four seams amenable to surface mining with dip angles of 2.6°-3.2°. Original mineable reserve was 617.00 Mt at average strip ratio of 1.00. Table 1 gives the salient feature of the mine.

Table 1 : Geological and Topographical features of the mine

Sl. No.	Particulars	Unit	Values
1.0	Thickness of Coal Seam and OB	m	10-80 5-20
1.1	Lower Kusmundu(Comb)	m	56.70 - 70.15
1.2	Lower Kusmundu(Top)	m	34.70 -44.85

Sl. No.	Particulars	Unit	Values
1.3	Lower Kusmundu	m	2.19 -24.50
1.4	Upper Kusmundu	m	24.69 – 35.82
1.5	Seam E&F	m	12.70 – 19.05
2	Specific gravity of the seams	Mcum/t	1.58
3	Avg. gradient of the Quarry floor		1 in 9 – 1 in 17
4	Excavation Category	Assumed	III
5	Average quality of Seam	Grade	E
5.1	Parting between lower Kusmundu (Bottom) and Lower Kusmundu (Top)	m	3 – 35.56
5.2	Parting between lower Kusmundu (Top) And Upper Kusmundu	m	12.17 – 78.63
5.3	Parting between E&F and UK	m	30.14 -62.12
5.4	Top O.B.	m	8.02 – 85.15
6	Excavation Category	Assumed	50% Cat III 50% Cat IV
7	Insitu Volume Weight	T/cum	2.25 – 2.40
8	Strike length of Quarry	Km	3 – 4
9	Dip Rise Width of Quarry	Km	2.6 – 3.2
10	Maximum Depth of Quarry	m	250
11	Surface area of Quarry	Ha	1002

The mining method practiced in the mine is cyclic method with shovel-dumper and drilling-blasting for overburden removal. Continuous surface miner extracts the coal for transportation by trucks. Electric Rope Shovels with buckets of 10 m^3 and 42 m^3 excavate and load OB onto dumpers of size 100 T and 240 T respectively. The dumper used in the mine have the following sensors attached: Tachometer, Odometer, Fuel level sensor, Fuel injection pressure sensor, Engine load sensor, Suspension pressure sensor, Engine temperature sensor, Engine speed sensor, Ground speed sensor, Transmission temperature sensor, Transmission pressure sensor, Hydraulic pressure sensor, Hydraulic temperature sensor, Load variance sensor and Pneumatic pressure sensor.

3. Methodology

Many researchers have worked in different areas of data acquisition, archiving, data retrieving and analysis for operational performance enhancement. However, the overall architecture of their work is very similar. Brzychczy et. al, 2020 identified the following steps common in these research works:

a. Defining the problem statement and formulating it mathematically (as far as possible).
b. Analyzing the processes involved and identifying the errors involved in the processes.
c. Redesigning the process to eliminate the errors (as far as possible).
d. Implementation/Application of this redesigned model considering various influencing factors.
e. Monitoring the implemented process through appropriate instrumentation and generation of data.
f. Based on the data analysis, further make necessary arrangements to improve the model.

For mining safety and productivity some of the tools deployed in the mines are briefly described in the following sections.

3.1 Computerized Maintenance Management System (CMMS)

The concept of maintenance has undergone many transformations over time. Currently, maintenance is a complex management process involving several organizational processes like production, quality, environment, risk analysis and safety (Lopes et. al., 2016).

For safe and productive mining, maintenance of machinery for their reliable services is very relevant. Maintenance performance has a strong impact on the mine's ability to sustain quality and timely supply of minerals to its customers. It is true that maintenance management requires a multidisciplinary approach with proper business perspective. However, management of such maintenance function effectively needs different information. This information is derived from the data acquired, transmitted, archived and retrieved for analysis to take necessary operational decisions. Thus an information system is developed. Recent advancement in ICT plays an important role to the organizational activities, such as the use of techniques to define the requirements of the users at various units in the system and to provide solutions to different process related issues. Information systems developed to support maintenance function are referred to as Computerized Maintenance Management Systems (CMMS) (Lopes et. al., 2016).

As discussed above, CMMS is a tool to support maintenance strategy based on information system. Such a system has a set of functions that process data to produce indicators to support maintenance activities (Cato et al, 2002). A CMMS normally involves the following:

a. **Assets Management :** that consists of recording all assets (or equipment) and a historical record of repairs and equipment parts list.
b. **Work Orders Management :** that allows setting and releasing of work orders to the maintenance technicians.
c. **Preventive Maintenance Management :** that supports the planning, scheduling and control of activities;
d. **Inventory control :** giving access to spare parts availability.
e. **Report Management :** CMMS processes large amounts of data and produces performance indicators.

Thus, in a CMMS the data is already generated and it is to be analyzed and necessary report is to be generated using the performance indicators after a prescriptive analysis.

3.2 Prescriptive Analysis

Prescriptive analytics adds value to businesses. It aims at suggesting or prescribing the best decision options in order to take advantage of the predicted future utilizing large amounts of data (Šikšnys and Pedersen, 2016).

Prescriptive analysis develop models incorporating the predictive analytics output and applies artificial intelligence, optimization algorithms and expert systems in a probabilistic context in order to provide adaptive, automated, constrained, time-dependent and optimal decisions (Basu, 2013; Engel et. al, 2012; Gartner, 2017).

Gartner, 2017 revealed that the prescriptive analytics has two levels of human intervention: decision support (e.g. providing recommendations) and decision automation. (e.g. implementing the prescribed action).

The effectiveness of the prescriptions depends on how well these models incorporate a combination of structured and unstructured data, represent the domain under study and capture impacts of decisions being analyzed (Basu, 2013; Šikšnys and Pedersen, 2016).

The general procedural approach for realizing prescriptive maintenance planning consists of four main elements (Matyas et. al, 2017). They are:

1. Data Acquisition and Pre-Processing
2. Data Analysis and Simulation
3. Reaction Model
4. Prescriptive Maintenance Decision Support System

However, for a prescriptive model to work one needs to have a predictive maintenance system initially, which generates prediction. Based on this necessary prescriptions can be generated.

3.3 Predictive Maintenance

Reliability, safety and maintenance costs are among the many benefits that gather a lot of attention in the industrial sector. Predictive Maintenance is a set of maintenance strategies which focusses on improving these factors so as to optimize the output of the system. A model of the strategies is given below (Jimenez et. al, 2020).

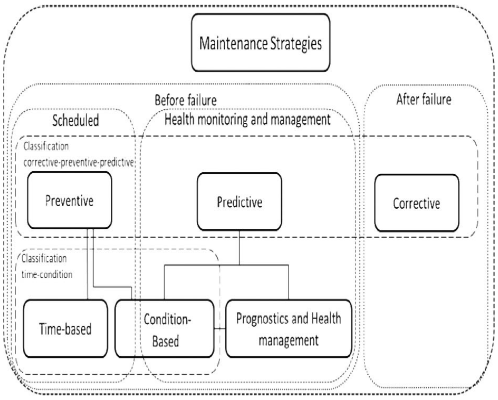


Figure 1 : Maintenance Strategies

After adopting these maintenance strategies, Key Performance Indicators or Performance Measurement Metrics are built to design the efficiency of the model and to point out its loopholes.

3.4 Key Performance Metrics

Production and Maintenance effectiveness are contradicting factors which should be given due consideration while designing an integrated planning process of a company. A Performance Measurement System is very crucial for Monitoring the performance of systems, quantifying the efficiency and effectiveness of actions and identifying the need for measures and adapting plans. A framework of maintenance performance measurement is as follows (Horenbeek and Pintelon, 2014):

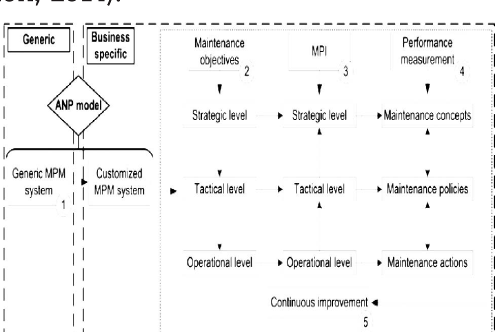


Figure 2 : MPM Framework

Here, the maintenance performance measurement (MPM) framework horizontally reflects the MPM process and vertically incorporates all organizational levels of decision making.

3.5 Data Acquisition

The data of the 240 ton dumpers was crude (in Excel files) and hence some preprocessing work had to be done. The duration of study was from Jan'20-Aug'20.

The maintenance breakdown data of fifteen 240 ton dumpers was procured. The fields of the records included different variables which are defined as given below:

1) M/c No.: Machine Number
2) SH: Shift Hours
3) WH: Working Hours
4) IH: Idle Hours
5) MH: Maintenance Hours
6) BD: Breakdown hours (BD is further divided into MARC BD (handled by service providers) and SECL BD (handled by SECL itself). SECL BD is further divided into SECL tyre (breakdown due to tyre) and SECL Accd. (breakdown due to other accidents).

For each breakdown the causes were collected from the log book as reported. The daily diesel consumption by each dump truck were also collected.

4. Analysis and results

Using the data collection for 217 days in a mechanized coal mine deploying 240T rear discharge off-highway trucks descriptive statistics were derived. Table 2 to Table 6 gives the working hours per day, idle hours per day, maintenance hours per day, breakdown hours per day and diesel consumption per day for 14 number of Caterpillar trucks.

Table 2 : Descriptive analysis data for working hours per day

	Working hours per day			
M/c No.	mean	stdev	median	range
1129	14.11	7.63	18.00	21.00
1131	10.88	8.21	12.00	21.00
1132	1.53	4.32	0.00	21.00
1135	10.44	8.32	11.00	21.00
1138	11.11	8.40	13.00	21.00
1139	12.79	8.35	16.00	21.00
1862	0.12	1.13	0.00	14.00
1864	13.58	8.26	17.00	21.00
1865	14.69	7.48	18.00	21.00
1866	11.09	8.66	13.00	21.00
1868	12.73	8.60	16.00	21.00
1869	10.89	8.85	14.00	21.00
1870	12.29	8.87	16.00	21.00
1874	13.89	8.17	18.00	21.00

Table 3 : Descriptive analysis data for idle hours per day

	Idle hours per day			
M/c No.	mean	stdev	median	range
1129	7.32	6.96	4.00	24.00
1131	8.45	8.27	4.50	24.00
1132	1.65	4.58	0.00	24.00
1135	7.63	7.88	4.00	24.00
1138	9.40	8.41	5.75	24.00
1139	7.27	7.21	3.75	24.00
1862	0.87	4.13	0.00	24.00
1864	6.63	7.12	2.75	24.00
1865	7.08	7.00	3.75	24.00
1866	5.28	6.17	2.75	24.00
1868	4.58	5.27	2.75	24.00
1869	5.69	6.74	2.75	24.00
1870	4.46	5.36	2.75	24.00
1874	7.48	7.57	3.00	24.00

Table 4 : Descriptive analysis for maintenance hours per day

	Maintenance hours per day			
M/c No.	mean	stdev	median	range
1129	0.56	1.79	0.25	14.00
1131	0.48	1.86	0.25	13.00
1132	0.09	0.63	0.00	7.00
1135	0.41	1.39	0.25	10.00
1138	0.46	1.63	0.25	13.00
1139	0.48	1.69	0.25	13.00
1862	0.00	0.00	0.00	0.00
1864	0.35	1.13	0.25	8.00
1865	0.47	1.38	0.25	9.00
1866	0.35	1.37	0.25	13.00
1868	0.36	1.29	0.25	10.50
1869	0.34	1.31	0.25	11.50
1870	0.34	1.16	0.25	8.00
1874	0.43	1.47	0.25	11.00

Table 5 : Descriptive analysis for breakdown hours per day

	Breakdown hours per day			
M/c No.	mean	stdev	median	range
1129	1.57	3.87	0.00	24.00
1131	3.74	7.13	0.00	24.00
1132	20.29	8.40	24.00	24.00
1135	5.08	8.51	0.00	24.00
1138	2.59	5.60	0.00	24.00
1139	3.01	6.97	0.00	24.00
1862	22.56	5.55	24.00	24.00
1864	3.01	6.62	0.00	24.00
1865	1.32	3.85	0.00	24.00
1866	2.16	5.11	0.00	24.00
1868	1.20	3.21	0.00	24.00
1869	1.95	4.76	0.00	24.00
1870	1.79	5.10	0.00	24.00
1874	1.75	4.81	0.00	24.00

Table 6 : Descriptive analysis for diesel consumption per day

M/c No.	Diesel consumption per day				
	count	mean	stdev	median	range
1129	172.00	2006.40	686.35	1950.00	4050.00
1131	136.00	1864.71	713.50	1900.00	3950.00
1132	25.00	1466.00	603.93	1450.00	3050.00
1135	131.00	2039.92	679.54	2050.00	3050.00
1138	141.00	2037.94	710.15	2050.00	3850.00
1139	155.00	2027.74	678.95	2000.00	3750.00
1862	1.00	1200.00	------	1200.00	--------
1864	161.00	1932.92	592.11	1950.00	2950.00
1865	179.00	1909.50	665.54	1950.00	3000.00
1866	133.00	2015.04	629.24	2000.00	2900.00
1868	149.00	1931.88	590.61	1900.00	3400.00
1869	134.00	1863.43	616.17	1800.00	3600.00
1870	144.00	1941.00	584.00	1850.00	2896.00
1874	162.00	1975.00	599.44	1975.00	2850.00

To visualize the data and to draw inferences from it Tableau is used. The visualizations are broadly divided into Machine wise analysis (to understand the usage of dumpers), generation of Key Performance Indicators or KPIs. The results obtained from the machine wise data analysis are shown in Figure 3.

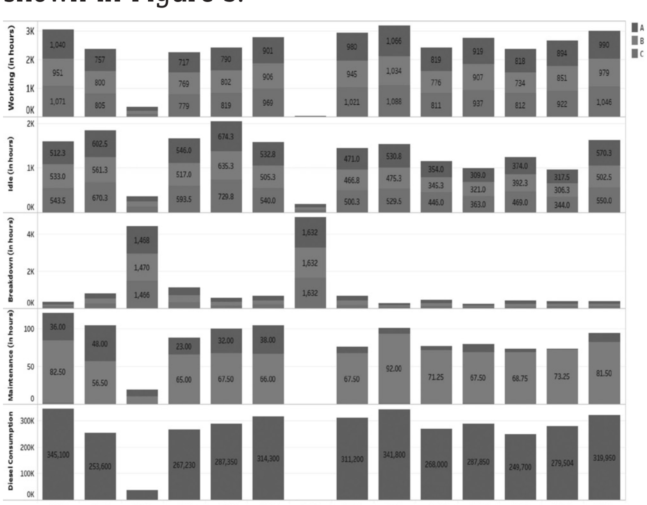


Figure 3 : WH, IH, BD, MH and Total Diesel Consumption

There are a total of 14 machines/dumpers with certain numbers. It is very clearly seen that 2 machines with numbers 1132 and 1862 were in breakdown state for almost the entire duration and hence consume very less fuel. The remaining machines have almost the same output and do not differ significantly. Also, changing the graphs to different shifts showed that only at shift A, diesel were filled in the machines. The machine with the most working hours is 1865. Apart from the two machines 1132 and 1862 all the other machines work. Machine 1132 and 1862 have the most breakdown hours and machine 1868 having the least breakdown hours. Machine 1138 has the most idle hours and apart form 1132 and 1862; machine 1870 is the least idle.

The shift wise analysis of the working hours showed that for the machines of series 1100, the working hours are maximum for shift C and for machines of the series 1800; the working hours are minimum for shift B. For the C shift the breakdown hours are relatively lesser. For almost all the machines the idle hours are maximum in C shift and minimum in B shift. The reason is that operators fatigue in night shift and are allowed to rest.

The key performance indicators obtained from the wise data analysis are shown in Figure 4.

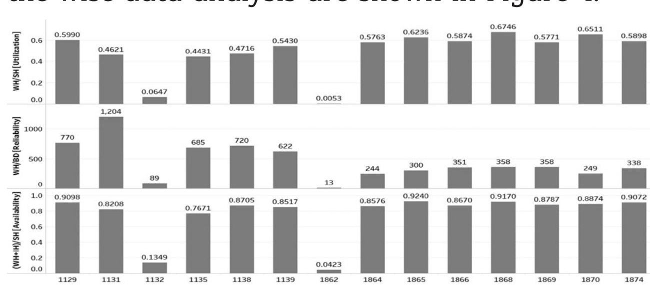
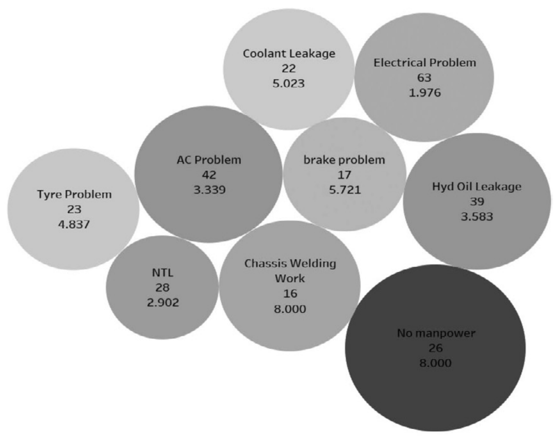


Figure 4 : Key Performance Indicators

The WH/SH ratio showed that the machines 1868 and 1870 are the most utilized machines. The WH/BH ratio showed that reliability of the machines. 1131 is the most worked machine for every breakdown hour and hence can be said to be the most reliable machine. The ratio of (WH+IH)/SH gives a measure of the availability of the machines. 1865 is the most available machine in the given time interval.

Moreover, the reasons of the breakdown were also analyzed and results obtained through are shown in Figure 5.



The colour and size of the bubble depicts the total Breakdown hours (red being the most and blue being the least).
First value shows the frequency of the particular problem.
Second value shows the average breakdown time for every time the problem occured.

Figure 5 : Causes of Breakdown

No manpower contributes to the most number of breakdown hours whereas electrical problems occur the most number of times. Chassis Welding Work and No manpower are also the causes which have the most number of breakdown hours for every time such problems arise. There are 327 different reasons of breakdown of which electrical problem (63 cases), AC problem (42 cases), hydraulic oil leakage (39 cases), NTL (28 cases), No manpower (26 cases) are some of the prominent ones.

5. Conclusion and Future Work

As our objective in this part was to analyze the dumpers, hence the preliminary conclusion that can be drawn on the analysis done is as follows: Of the 14 dumpers, the dumpers with numbers 1132 and 1862 are not utilized and are considered as outliers.

The dumpers (other than 1132 and 1862) considering different aspects can be ranked as given in the table below:

Table 7 : Ranking of dumpers

Rank	Diesel Consumption	Working Hours	Utilization	Reliability	Availability
1	1869	1865	1868	1131	1865
2	1131	1129	1870	1129	1868
3	1135	1874	1865	1138	1129
4	1866	1864	1129	1135	1874
5	1870	1139	1874	1139	1870
6	1138	1868	1866	1869	1869
7	1868	1870	1869	1868	1138
8	1864	1138	1864	1866	1866
9	1139	1866	1139	1874	1864
10	1874	1869	1138	1865	1139
11	1865	1131	1131	1870	1131
12	1129	1135	1135	1864	1135

An important conclusion here is that, if the reliability of the dumpers is considered then the dumpers with the series of 1100 are better as compared to that of series 1800. This implies that the working hours after every breakdown hour is better for the 1100 series dumpers as compared to that of the 1800 series.

Conversely, if the utilization and availability of the dumpers are considered then the dumpers of the series 1800 are better than that of 1100. This means that the 1800 series dumpers are more engaged in working and are operated more frequently than the 1100 series dumpers.

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PROSPECTS AND CHALLENGES OF MINERAL BASED INDUSTRIES AND UTILIZATION OF WASTES FOR MAKE IN INDIA

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Introduction

Large mineral based industries like iron and steel, aluminium, cement and base metals are fairly well developed and established in India, however, small and medium sized enterprises mainly focussed on the value addition of minerals / ores/ industrial minerals are quite neglected in the country. These industries have vast potential for country like India, which has well qualified manpower, small to medium sized entrepreneurs and necessary technical skills more over they may safeguard our forex reserve by making import substitute products. All these elements make the mineral based industries suitable candidates for the development and promotion of the Government sponsored 'Make in India' initiative. Keeping this in view, International Mineral Business Development conference (MBD-2022) is being organized in Nagpur, India during March 2-4, 2022 in cooperation with Indian Bureau of Mines (IBM) and Federation of Indian Mineral Industries (FIMI). The main objective of this conference is to highlight the major advances in value addition of minerals and utilization of wastes, which directly promotes the Government of India initiative of 'Make in India' and Atmanirbhar Bharat.

Value Addition – Industrial Minerals

Globally, the mineral industry is continuously on the move due to technological progress leading to the development of value-added products and new usages and also to changing supply of raw materials and environmental concerns.Industrial minerals surround us everywhere in the normal life; in houses, paper, plastics, paints, glass, ceramics, cars, pharmaceutical industries and even as additives in food. As the world consumption of manufactured products increases, so will the production of industrial minerals, and additionally new end-uses are being developed. Typical for the industrialised countries, the production of minerals is not limited to construction materials but includes a great number of other minerals mainly exploited for niche products and export purposes. Concerning India, there are several reasons for these positive developments;

1. The existence of a diversified geology, including many big mineral and coal deposits,
2. A good geographic position relative to the most important markets,
3. Along coastline with excellent shipping and export possibilities,
4. The increasing role of multinational companies, adding knowhow and market access
5. The availability of basic infrastructure, qualified manpower and young entrepreneurs

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6. Reforms in the mineral sector by mandating auction of mineral concessions to improve transparency and many more

Figure-1 provides basic steps in the production of value-added mineral products from the raw minerals.

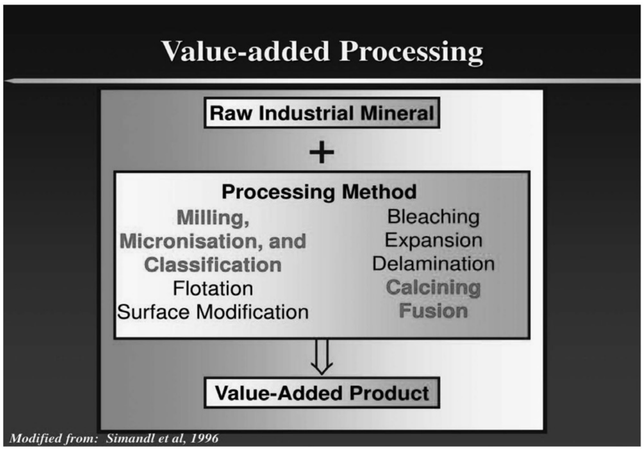

Figure-1 : Basic Processes for Value Addition of Minerals

At present the mineral based industries face multiple challenges, namely,

i. Dwindling production and deep seated mining,
ii. Fast depletion of high-grade resources and lowering of threshold value of minerals,
iii. Changing policies of the exploitation and processing of minerals,
iv. Wavering prices of mineral commodities due to International demand supply scenario and political instabilities,
v. Restricted (non-liberal) investments in the mineral sector and long gestation period.

Therefore, in order to make mining more attractive, it is necessary to make optimum utilization of the resources, develop the technologies for extraction of as many products and by-products as possible, and also create the value-added products from the mining wastes. The Government of India has introduced "Make in India" and Atmanirbhar Bharat initiatives for encouraging the industries and entrepreneurs to come forward and create a win-win situation for the mutual benefits.

At this backdrop, it is necessary for the stakeholders including entrepreneurs, industries, R & D institutions, and academia to deliberate on the present-day challenges faced by the mineral industry. MBD-2022 provides excellent opportunities and invites technical papers and presentation from the leading experts and companies on industrial minerals, mineral based products, effective use of vast coal resources such as gasification and latest developments and utilization of wastes of mines and mineral processing industries.

⏩ Industrial Minerals of India and Value-Added Products

The country is endowed with huge resources of many metallic and non-metallic minerals. Mining sector is an important segment of the Indian economy. Since independence, there has been a pronounced growth in the mineral production both in terms of quantity and value. India produces as many as 87 minerals, which includes 4 fuel, 11 metallic, 22 non-metallic, 3 atomic and 23 minor minerals (including building and other materials)[1]. The major metallic minerals currently mined in India are iron, bauxite, manganese, copper, lead, zinc, tin, silver, gold and scores of industrial/ minor minerals. The emphasize of present conference will be on non-metallurgical application and uses of these metallic minerals. For example, there are several non-metallurgical uses and applications of bauxite in making refractory, abrasives, ceramics and minor products. In non-metallic minerals, India ranks second in barytes, bentonites, talc, steatite, pyrophyllite; 3rd in chromite, coal, and

1. https://www.mines.gov.in/writereaddata/UploadFile/National_Mineral_Scenario-converted.pdf

lignite; 4th in andalusite, sillimanite, kyanite etc. India ranks 4th in the list of minerals producing countries after China, USA, and Russia. Common industrial minerals mined in India according to IBM (2018) include following:

(1) Metallic (Ferrous) minerals: Iron, Manganese, Chromite
(2) Metallic (Non-Ferrous) minerals: Bauxite, Copper-Lead-Zinc, Platinum Group Metals
(3) Gems and Precious minerals: Diamond, Gold, Emerald, Ruby, Safire, Silver
(4) Refractory minerals: Andalusite, Graphite, Kyanite, Magnesite, Sillimanite
(5) Ceramics and Glass minerals: wollastonite
(6) Strategic minerals: Cobalt, Molybdenum, Nickel, Rare Earth Elements, Tin, and Titanium
(7) Other Industrial minerals: Asbestos, Borax, Diatomite, Fluorite, Limestone, Marl, Perlite, Rock Salt, Vermiculite, Zircon
(8) Minor Industrial minerals: Ball Clay, Barytes, Bentonite, Calcite, Chalk, China Clay, Corundum, Diaspore, Dolomite, Dunite, Feldspar, Fire Clay, Fuller's Earth, Granite, Gypsum, Laterite, Marble, Mica, Ochre, Pyrophyllite, Quartz & Silica Sand, Quartzite, Talc/Steatite/Soapstone, Shale, Slate

As a common practice, one specific mine focuses on specific metal and the rest of the minerals and low grades are considered waste and disposed-off as such. But some of these waste products contain valuable minerals/metals that can be recovered and used sustainably. Instead of being simply dumped, mine tailings can be re-mined/ processed to recover valuable minerals/ metals. Re-mining tailings extends the operating life of existing mines. Re-visiting mine tailings have more economic and environmental benefits than developing new greenfield mines. The value-added material can also be recovered from mining waste. Few examples are cited here:

a. Selective enrichment and separation for the recovery of copper and iron components from Daye copper converter slag
b. Utilisation of red mud from Bayer processing of bauxite
c. Spent pot lining from aluminium smelting
d. Fly ash from power generation, slags from smelting operations and the use of wastes in cement, geopolymer concrete etc.

Keeping these in view, it is proposed to create website and depository of all the information / data on availability and quality of wastes /rejects of mineral industries so that these data can be used by interested entrepreneurs.

Examples of Mineral Based Products

Keeping in view the industrial mineral resources of India, some of the value-added mineral products are named here as examples.

Baryte	Un-ground Baryte ROM	Ground & Classified API & OCMA Grade	Fine ground / classified Filler Grade	Chemically Produced filler grade	Chemically Ultra-purified Barium chemical
Bauxite	Crushed/screened Dried ROM	Heat treated Calcined bauxite	Chemicallyproduced Al Chemical	Heat treated Calcined Alumina	Fused Fused & sintered alumina
Bentonite	Ground &classified Drilling, foundry, civil engineering grade	Ground &classified API & OCMA Grade	Chemically Treated Soda-ash treated montmorillonite	Chemically Treated Acid activated montmorillonite	Chemically Treated Organoclays
Chromite	Crushed/ Screened Metallurgical Ore	Ground &classified Refractory, foundry & chemical ore	Find ground / classified Chromite foundry sand	Chemically Produced Chrome pigments	Fused Ferrochrome

Dolomite	Crushed/ Screened Aggregate	Aglime, glass-grade, filler-grade	H.M. & Floated Chemical metallurgical (Dolime)	Heat Treatment Metallurgical (Doloma)	Chemically Produced Magnesia Chemical
Feldspar	Crushed/ Screened Non-commercial	Floated Glass-grade	Floated High-potash grade	Fine grinding / classification Ceramics/ Filler grades	
Fluorspar	Floated Metallurgical-grade	Floated Acid-grade	Chemically Produced Aqueous hydrofluoric acid	Chemically Produced F chemicals (fliosilicic acid, synthetic cryolite)	Chemically Produced Fluorocarbons
Garnet	Crushed /Screened Water Filtration	Classification Blasting abrasive & water jet cutting	Heat treatment Abrasive grain grade garnet		
Graphite	Graded / Classified Amorphous Powder	Hand Sorted Small flake crystalline lump (80-95%C)	Hand Sorted or Floated Medium flake crystalline lump (80-95%c)	Hand Sorted or Floated Large flake crystalline lump (80-95%C)	Hand Sorted or Floated Crystalline lump (92-95%C)
Gypsum	Crushed/ Screened Wallboard/Cement	Ground / Classified Agriculture Grade	Heat treated (calcined) Plaster	Ultrafine Ground Filler	
Kaolin	Ground / Classified Dried Kaolin	Fine Ground / Classified Dry-Grade& air Floated (filler grade)	Fine Ground/ Classified Wet-Grade & water washed (filler and coating grade)	Ultrafine Ground Uncalcined delaminated paint grade	Heat treated (calcined) Water-washed & calcined paint & paper grade
Kyanite	Floatedand Magnetic Separated Raw Kyanite (54-60% Al2O3)	Heat Treated Calcined kyanite (59-62% Al2O3)	Magnetic& H.M. Sep Andalusite (57-60% Al2O3)	Mag. & Heavy Media Separated Sillimanite (70%Al2O3)	
Limestone	Crushed/ Screened Aggregate/Aglime	Glass/filler Grade	Ultrafine Filler Grade	Chemically Produced PCC/UF filler	Surface treatment Filler
Lithium	Heavy Media Separation Petalite Conc. (4.2% Li2O)	Floated Heavy Media &/or Mag Sep. Glass-grade spodumene (5-6.8% Li2O)	Floated Heavy Media &/or Mag Sep. Spodumene Conc. (7.3-7.6% Li2O)	Chemically Produced Lithium Carbonate (40.4% LiO2)	Chemically Produced Lithium Chemicals (bromide, chloride, fluoride, nitrate, sulphate)
Magnesite	Crushed/screened H.M.&/or Mag Sep. Raw magnesite	Heat Treatment(calcined) Caustic calcined magnesia (agricultural grade)	Heat Treatment (dead burned) Dead-burned magnesia (Natural to synthetic)	Chemically Product Magnesia Chemicals (chloride, carbonate,hydroxide, sulphate)	Fused/electrolytic Fused Magnesia
Manganese	Ground &classified Metallurgical-grade manganese ore(35-58% Mn)	Heavy Media Separation Battery and Chemical (74-85% MnO2) Manganese Ore	Screened chemical leaching electrolytic Synthetic or electrolytic manganese dioxide (EDM) (85-92% MnO2)	Chemical Product Mn chemical (K permanganate, Mn acetate, carbonate chloride)	Fused High-carbon ferromanganese

Mica	Hand split & graded Sheet Mica	Floated ground& classified Drilling-mud grade	Floated ground Joint-cement grade	Floated Dry Fine ground (micronized & classified) Paint/plastic filler grade	Floated wet ground& classified Filler Grade
Neph. Syenite	Crushed/screened Non-commercial	Magnetic Separation Glass	Fine Ground/ Classified Ceramics	Ultrafine ground/ Classified Filler	
Olivine	Crushed/screened Blast furnace grade	Ground / Classified Refractory grade	Fine Ground Foundry sand	Ultrafine ground Olivine flour (Filler-grade)	
Phosphates	Washed, Screened &Floated Crude phosphate rock	Chemically Produced Acidulation of P rock with sulfuric acid Phosphoric acid 80-85% P2O5 (commercial & technical grades)	Chemically Produced Acidulation of P rock with sulfuric acid or phosphoric acid Single (18-20% P2O5) or triple superphosphate (44-46% P2O5)	Chemical Product & blended Phosphate ammonia mixed fertilizers (MAP, DAP)	Chemically Product Phosphate chemicals (e.g., STPP, P pentoxide) including food-grade
Pyrophyllite	Hand selection & crushed/ screened White cement (9-12% Al2O3)	Hand selection & ground/classified Blended Ceramic Grade	Hand selection & ground/ Classified Blended High-grade refractory grade Glass-fibre grade (18-21% Al2O3)	Hand selection & fine ground/classifiedand blended Filler-grade (20-21% Al2O3)	Hand selection & ultrafine ground/ classified and blended Filler-grade
Salt	Feedstock salt Salt in brine	Heat treatment Evaporated/ bulk	Agglomerated Pressed Block	Chemically Concentrated Chemical Grade	Chemically Ultra-purified USP sodium chloride
Silica Sand	Crushed & screened Construction Sand	Ground/Classified Foundry, filtration, Chemical, metallurgical, abrasive sand	Floated and ground/ classified Flat & container glass grade	Floated and fine ground/classified Ceramic, fiberglass, scouring powder	Floated and ultrafine ground/classified Silica flour, Filler in paint plastic and rubber
Soda Ash (Trona)	Crushed &screened Non-commercial	Calcined Calcined trona	Chemically Concentrated Dense soda ash (glass)	Chemically Concentrated Light soda ash (detergent)	Chemically Ultra-purified Sodium carbonate decahydrate (chemical)
Talc	Floated or crushed/ screened Crude talc	Floated or fine ground/ classified Filler and ceramic grade	Floated or ultrafine ground/ classified Micronized talc pitch-control talc	Floated or ultrafine ground/ classified Chemicallyultrapure Cosmetic grade talc	Floated or ultrafine ground/ classified Surface treated Filler in plastic
Titanium	Magnetic/gravity & electrostatic separated of heavy mineral fraction Ilmenite (54%TiO2)	Groundgravity separated, roasted & smelted ilmenite in an electric arc furnace Titanium slag (75-85% TiO2)	Reduction of ilmenite at high temperatures with coal in a rotary kiln Synthetic rutile (91-96% TiO2)	Chlorination of high-titania material at high temperature Titanium tetrachloride (TiCl4)	Chemicallyproduced from ilmenite/ rutile via sulfuric acid or chlorination Reduce TiCl4 TiO2 pigment Ti sponge

Vermiculite	Crushed/screened/ blended/gravity separated and floated Raw vermiculite concentrate	Heat Treatment Exfoliated vermiculite			
Wollastonite	Mag.separation and ground/classified Low aspect ratio (LAR) Ceramic	Special fine ground/ classified High aspect ratio (HAR) Filler	Special ultrafine ground Surface treatment High aspect ratio (HAR) Filler		
Zircon	Magnetic/gravity and electrostatic separated Standard and premium grade zircon	Special fine ground/ classified Zircon flour (ceramic opacifier)	Chemicallyultrapure Zirconium oxide electronic, insulating, stabilized	Reduction of ZrCl4 Zirconium powder, sponge, sheet, bars, etc.	

Figure 2 provides an example of an integrated TiO_2 value chain.

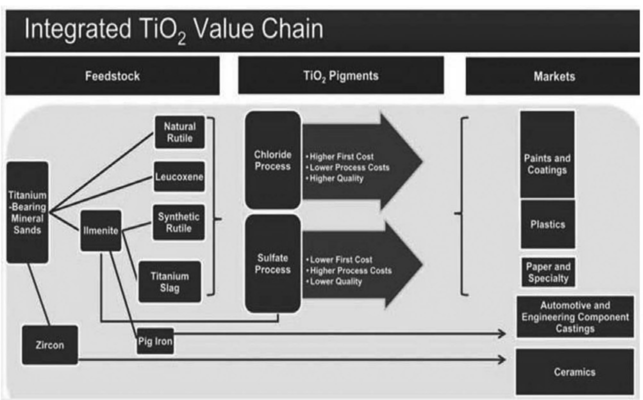

Figure-2 : Value Added Products of TiO2

Figure-3 shows how the value of mineral increases with product type and quality.

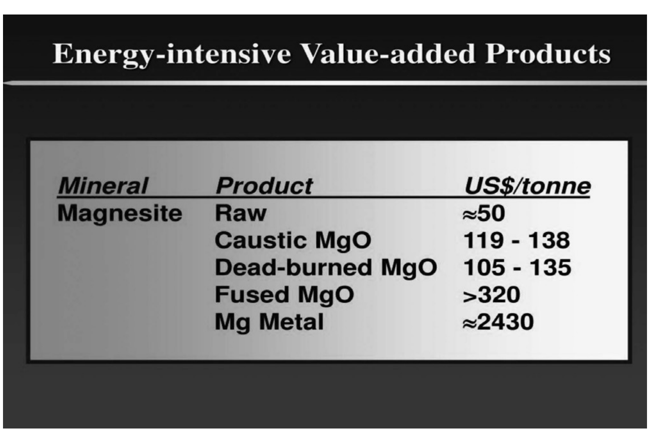

Figure-3 : Example of Magnesite Products and Prices

⏩ India's Minerals Based Companies and their Products

In India, there are several leading manufacturers of value-added mineral products and some of them are exporting these in the world market. A comprehensive list of leading Indian producers of main industrial minerals is provided here in the table given below.

Table : Major Value-Added Mineral Producers of India

Sr. No.	Mineral	Leading Producers	Main Products
1.	Barytes	Gimpex, 20 Microns, Alcore Minerals	White and Grey Barytes Lumps, Barytes powder, Ceramics andMicronized Barytes etc.
2.	Bauxite	AshapuraMinechem, Saurashtra Calcine, CUMI (Carborundum), Calderys (Imerys), Vesuvius India etc.	Calcined bauxite, Brown fused alumina, Ceramics andProppants etc.
3.	Bentonite	Ashapura, Gimpex-Imerys, 20 micron,Trimex Industries Pvt.Ltd., Kandla Agroand chemicals Pvt Ltd	Bentonite Clay, Bentonite lumps,

Sr. No.	Mineral	Leading Producers	Main Products
4.	Chromite	The Orissa MiningCorporation Ltd, The Tata Steel Ltd, Balasore Alloys Ltd, Indian Metals & Ferro Alloys Ltd, Ferro Alloys Corporation Ltd, Bhakti International, Haibru Export Private Limited and Zenith Steels	Chromite Ore Sand, Ferro-chrome, Sillico-chrome, Charge-chromeand Chromium metal etc.
5.	Dolomite	Ashapura China Clay Pvt. Ltd., Aarjay Minerals, Steel Authority of India Ltd, Bisra Stone Lime Co. Ltd,Rastriya Ispat Nigam Ltd, Tata Steel Ltd, Mysore Minerals Ltd, AravaliPolyartPvt. Ltd, Dolomite Mining Corp.	Fertilizer, Glass, Bricks, Ceramics, etc.
6.	Feldspar	A & J Microns Pvt. Ltd., Aarjay Minerals, Cementation India Pvt Ltd, Earth Chem Exim Pvt Ltd,Friends Salt Works & Allied Industries, Karnataka Silicates, Kedar Industries,Leuco Microns Pvt Ltd,	Feldspar Powder, Potash Feldspar Lumps, Potassium Feldspar andSoda Feldspar etc.
7.	Garnet	Trimex Sands Pvt. Ltd, Indian Rare Earths Ltd, Transworld Garnet India Pvt. Ltdand V.V. Minerals	Gem Stones, Garnet Abrasive and Garnet Sand etc.
8.	Graphite	Tamil Nadu Minerals Ltd, Graphite India Limited (GIL) andTirupati Graphite	Graphite Moulds, Graphite Tubes and Graphite Bricks etc.
9.	Gypsum	Rajasthan State Mines and Mineral Ltd., Thoothukudi, Tamilnadu.	Cement, fertilizer,Moulds etc.
10.	Kaolin	AshapuraMinechem Ltd.	Paper, Rubber, Paint etc.
11.	Kyanite	PavriKyaniteMine (Maharashtra) Nawargaon-ChowaKyanite Mine (Maharashtra)	Refractories, ceramic products etc.
12.	Limestone	Nandini Limestone Mines, (Chattisgarh) Bhawanathpur Limestone mine, Jharkhand Jabalpur (M.P.) & Satna(M.P.) Cuddapah (Andhra Pradesh)	Food additive, Paint, Paper, Rubber, Glass and Plastic etc.
13.	Lithium	KhanijBidesh Ind Ltd.	Batteries.
14.	Magnesite	Tamil NaduMagnesite Ltd, (Tanmag)	Refractory material, fertilizers etc.
15.	Manganese	Bharveli manganese mine, Balaghat (M.P.), Nagpur-Bhandara region (Maharashtra), Tentulidihi Manganese Ore Mining, Dengula, (Orissa).	Clear glass, Paint, Filler in dry cell Batteries, etc. MnO as cattle feed industry
16.	Mica	Gudur Premier Mica Company,Andhra Pradesh, Aravalis (Rajasthan), Koderma (Jharkhand).	Electrical insulators in electronic equipment, Glassblushes, lipsticks, lip gloss, eye liner, eye shadow, foundation, glitters, mascara, nail polish, toothpaste, etc.
17.	Olivine	Maxworth Minerals Pvt Ltd, Andhra Pradesh.	Refractory bricks, Mould, etc.

Sr. No.	Mineral	Leading Producers	Main Products
No.	Phosphates	Jhamarkotra Rock Phosphate Mine (RSMML), Udaipur	Fertilizer, Water-based paints and coatings, Metal polishes, Flame retardants, Processed foods, Personal care products, pharmaceutical products etc.
19.	Talc	Golcha Group, Rajasthan, SKKU Minerals India Pvt Ltd. Rajasthan	Paint, Rubber, Food, Electric cable, Pharmaceuticals, Cosmetics, Ceramics, etc.
20.	Pumice	Siddhivinayak DyechemPvt. Ltd. Mumbai	Medicine, Soap Bar, Concrete, Cinder Block, etc.
21.	Zircon	V.V.Mineral Pvt. Ltd. Tamil Nadu.	Ceramics.
22.	Quartz	Vinayaka Microns (I) Pvt. Ltd. Rajasthan. Veejee Mines and Mineral, Andhra Pradesh. Sharma Basaveshwara Mining Co. Karnataka. Vidhatri Mines and Minerals, Andhra Pradesh	Ceramics, Glasses, Alloy Steel, Cement, Fertilizer, Foundry, etc.

⏩ Mineral Business Development (MBD) Conference & Exhibition

Keeping in view, the importance of mineral based products and valorisation of mineral waste in the world, the Mineral Business Development (MBD-2022) conference and exhibition is being organized in India by a team of mineral specialists. Despite having vast mineral resources and qualified technical manpower, India is lagging behind in the production of value-added mineral products and import several high-end items, which can be produced in India. Country offers excellent opportunities in attracting foreign investments and in export of value-added mineral products.

MBD-2022 will provide a platform for the mineral producers, technology / equipment suppliers and R&D organizations to highlight latest technological developments in mineral processing and its commercialization. The conference will seek to highlight the strategic linkage between the technological and commercial sides of the mineral industry from discovery to exploitation and production of value-added products. The emphasis of this conference will be to highlight potential of industrial minerals, non-metallurgical products and high-end mineral based industries. This vital industrial area was neglected in the country so far and this is the right time to work on the mineral based value-added products in India.

The organizing committee of MBD-2022 invites all stakeholders including mine owners, mineral producers, technocrats, R&D institutes and entrepreneurs around the world to come together and interact for the development of this vital industry. This conference will provide an excellent opportunity to interact with mineral producers, buyers, traders and experts in the field of minerals and mineral based products. Please visit website http://www.mineralinfo.net for details.

INTERNET OF THINGS BASED ENVIRONMENTAL MONITORING SYSTEM IN UNDERGROUND MINES : A BRIEF REVIEW

Sanjoy Gorain[1], Joydeep Dutta[2], Arindam Biswas[3], Anand Nayyar[4], Noor Zaman Jhanjhi[5]

Abstract :

Environmental conditions such as hazardous mine gases, temperature, fire, dust, humidity, roof falls etc. affect the productivity and safety of the underground mines heavily. These conditions if not taken care of properly may even result in huge casualty. Hereby, the effective monitoring of such underground mine is essential for the safe production from the mines. Nowadays, where wireless sensor networks are proving their significance almost in every sector of human life, the same has already been started being deployed in the advanced countries for the aforementioned purpose. The deployed sensor can easily monitor the various environmental parameters and transmit their respective measurements to the centrally situated server for further decision making ensuring safety while mining. Moreover, with advent of Internet of Things (IoT), efficiency of such system can be made to achieve new heights via suitable integration. In this project, we aim to develop a dynamic framework consisting of sensor-enabled IoT devices to be employed in the underground mines which facilitates the overall objective of safe production in four steps - Data Acquisition, Transmission, Analysis, and Application. Data Acquisition refers to the process of acquiring environmental parameters; Transmission and Analysis ensures inferring the site-safety; and, Application executes the respective decision.

Keywords : Wireless Sensor Networks, Internet of Things, Mining, Safety.

1. Introduction :

Mine safety has always been a great concern for the researchers for the decades due to the risks and challenges associated with the mining costing the miners' life at the most. Earlier, in order to achieve the continuous online monitoring, wired communication was implemented; but, due to severe environmental characteristics inside the underground mines, the wired communication failed as it had to cope with a number of issues viz. cable impairment, high failure rate, and inconvenient system maintenance etc. Then, with the evolution of Wireless Sensor Networks (WSNs), a variant of the same was proposed duly for this context with the name Wireless Underground Sensor Networks (WUSNs) [1-3].

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Since its inception, WUSN has evolved as a great tool for the environmental monitoring in the underground mines. Sensors are buried deep in the mines to capture the relevant surrounding measures like gas-leakage, temperature and humidity etc. so that the most appropriate course of actions can be followed accordingly in order to prevent any financial or human loss. However, to improve the effectiveness of such monitoring systems, what is needed at the most is the huge deployment of nodes covering almost every inch in the mine. More illustratively, from the spatial distribution of mining equipment across the roadways, wall-faces, and chambers etc. to the particular localization of the miners; and, from the underground environmental parameters to the mining stress data, one needs to employ data acquisition units for recording and utilizing the respective data sets [4].

To satisfy this requirement of huge data set generation, current technologies have been found insufficient due to a number of technical limitations. And, here comes the IoT, playing a key role in achieving the aforementioned [5-8]. IoT, being a set of huge number of sensing devices, signal frequency labels, and signal recognizer, can efficiently identify, locate, and track the real-life objects in real-time [9-10]. IoT is a technology which makes use of a number of existing technologies viz. WSNs, computer network technology, signal frequency identification technology, and database technology in order to achieve a well-specified objective like here is the intelligent and safe mining [11-18]. As per the proposal, various IoT devices such as sensors etc. can be installed at the designated places in the mine for the generation of operational and managerial data to ensure the safe production.

2. Literature Survey :

Significance of robust and efficient communication infrastructure is quite obvious in every industry; however, when it comes to the mining industry, its role become more crucial as it can not only minimize the economical losses, but also can save the priceless human-lives. With the help of pre-alarming system built on the real-time data from the deployed strong communication system, the site can be evacuated or preventive actions can be executed for saving lives of the miners. Also, with wise use of the data received from the communication system, overall mining productivity can be improved to a huge extent.

Replacing the wired infrastructure, wireless took over as it can easily cope with the extreme environmental conditions present in the underground mines. Moreover, nowadays, wireless sensor network integrated internet of things are being developed and deployed for the effective and smart mining. Such systems consist of environment sensors (to read temperature, humidity, and gas-leakage etc.) buried underground and within the surfaces of mines, portable and wearable sensors being carried by the miners in the mines, sensors monitoring the working surrounding and current status of the equipment being employed, and location-sensors to keep track of the miners to deal with any emergency circumstances. With the help of these sensors' real time data, analytics are developed for the predictive site-maintenance, early alarm provisioning, and safety improvement. However, the main challenges in implementing these are due to the extreme in-house conditions at the respective sites. As the fundamental components of such IoT based systems are sensor nodes suffering with some major constraints like limited processing, limited storage, and limited power, the overall performance of the system may also get affected.

In an attempt to realize the aforementioned solutions based on IoT, a number of works have been reported there in the literature viz. [19-12]. In [19], the authors, T Jiang*et al.*, had developed a ZigBee-Wireless Sensor Node based coal mine monitoring system which employed multi-sensor nodes for monitoring the environmental parameters. Here, like the traditional wireless sensor networks, nodes were sending their sensed information to the centrally located base station for further processing and instruction. However, the solution was not scalable to the current requirement of mining industry. In an attempt to implement IoT in the coal-fields while applying the concept of cloud-computing and big data, a comprehensive safety system has been proposed by W Yaqin*et al.* [20]. The proposed system keeps a complete eye on the production from the mines taking safety measures into account. The system serves the target mines from raising alarms for unsafe working conditions to rescuing the miners in emergency scenario. Moreover, in the works reported in [21-24], researchers have deployed different gas-sensors in order to detect the leakage of hazardous gases in the mines ensuring the safety of workers.

T. Wang *et al.* [25] have proposed a cloud-computing based framework for the wearable devices worn by the miners while being in the mines. Using their proposed framework, they have already demonstrated the significance of such systemsvia real-time monitoring of the work-environment in the underground mines.

Furthermore, an automated system was proposed by M.A. Moridi *et al.* in order to develop a monitoring and operation management system for the underground mines via an integration of the technologies such as Wireless Sensor Networks and Geographic Information System [26]. The proposed system is not only effective in emergency communication in case of unsafe working conditions, but also automates the operation of mining ventilation system according to the in house temperature, humidity, and gas concentration values received through the deeply deployed respective sensors.

In their attempt to further explore the possibilities with the technologies such as IoT, WSN, and the Artificial Neural Networks (ANN), A. H. Soomro *et al.* have developed a monitoring system for the underground coal mines [27]. In the aforementioned scheme, an alarming system along with the miners' positioning system has been proposed which employs the various sensors in the mines predicting the dangerous and life-threatening working conditions in the close proximity of the miners through the application of ANN.

In [28], an IoT based smart system was developed by the team, S Ankit *et al.* with the name Smart-SAGES for the underground coal-mines. Smart-SAGES is an improvement of the work Self-Advancing Goaf Edge Support (SAGES) [29] in which the objective of SAGES i.e. protecting the roof-collapse during the coal-extraction by providing the supports at the working front has been achieved remotely via a suitable exploration of communication technology particularly that of IoT. Through the detailed insight retrieved via the various sensors deployed, decision making process is automated for executing the prompt actions keeping the workplace safe. Similarly, technologies like IoT and WSN have also been used to develop smart helmet ensuring the miners' safety and hence further improving the mining productivity in turn [30-32]. In developing these systems, devices sensing temperature and humidity, air quality, and helmet removal etc. have been used accordingly.

Progresses have been regularly noticed in the fields of underground coal mines and petroleum; however, no significant work has been observed of implementing IoT based Mining support system for other mines like that of minerals and non-ferrous metals to the best of our knowledge. Hereby, in the project being applied here, the domain expertise of the team (viz. in IoT, Mines, Communication, and Networks) will be utilized to develop a specialized environment-monitoring mining support system for the mines of minerals and non-ferrous metals which meets all the aforementioned objectives while keeping the inputs from the till date literature available in the mining context into consideration.

3. Conclusion and future work :

The authors are intended to develop an Environmental Monitoring System - measuring effectively the various environmental parameters affecting the productivity such as temperature, humidity, leakage of hazardous gases from the workplace, and roof falls etc. It will be a User & Equipment Tracking System - keeping the records of the respective locations of miner as well as equipment and an Alarming System - raising alert signals to the management and the miners in case of emergency due to either unsafe environmental conditions or unsafe mining practices and an Emergency Evacuation Guiding System - leading the miners to leave the place safely in case of some mishaps.

4. Acknowledgement :

Authors would like to thanks KNU UGC-STRIDE and DST-ASEAN (Grant No: CRD/20201000284) for providing financial assistant to carry out this research work.

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APPLICATION OF LP AND MLR TECHNIQUES TO DETERMINE OPTIMAL OVERALL UTILISATION OF HEMM AND OVERBURDEN PRODUCTION IN OPENCAST MINE

Arunava Mondal*, Sumit Kumar Singh*, Netai Chandra Dey*

Abstract :

Overall utilisation of the fleet comprising of rear end dumpers and shovels for removal of overburden in an opencast coal mine has been studied. The average production of overburden is 10500 m^3 and the match factor has varied between 0.64 and 1.77. A multiple linear regression (MLR) model to estimate the volume of overburden removed in a shift on the basis of overall utilisation of dumpers and shovels has been developed. The model is found to be satisfactory given the fact that production of a mineis dependent on a myriad of factors. Optimum removal of overburden possible in a shift, by operating the fleet at a predetermined match factor has been estimated along with optimum utilisation of HEMM(s) using linear programming (LP) technique.

Keywords : overall utilisation; opencast; coal mine; match factor; optimisation

1. INTRODUCTION

India, in the recent years, has seen rapid urbanisation and growth in the manufacturing sector. Minerals are the primary resources for the manufacturing sector as coal is for the power sector to produce electricity which in turn fuels the manufacturing and production process. Therefore, the Government of India (GoI) is giving a major thrust on increasing the annual extraction of coal and other minerals. To that end, the GoI has considered to lease out more coal blocks for reaching the target production of 1 billion ton of coal per year. More than 90% of India's coal production is by opencast mining method and has seen positive growth over the last decade. [1]

However, just opening up new coal blocks to mining companies is not the solution to the problem. The production from the existing mines also needs to be ramped up if India is to meet its ambitious targets.

Overburden removal is necessary to increase the coal production from an opencast coal mine. Mining Companies aim to increase the production from their mines by better utilisation of existing Heavy Earth Moving Machines (HEMM) as capital expenditure for new machinery would increase their operating cost, owning cost and the expenditure on training the workers.

Six major losses are seen with regard to the shovel-dumper combination used in the opencast

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mines. Significant decrease in the availability of the machinery is caused due to downtime hours for equipment failure or due to overhauling and setup of costly machines. In addition, the performance of the HEMMs is severely affected, by the idle hours out of minor or major stoppages or not maintaining the recommended speed by the operators. Furthermore, reduced yield or quality defects sabotages the overall equipment effectiveness of the equipment. [2]

Most of the opencast coal mines in India use Shovel and Dumper to load and haul the overburden after blasting. The loading and hauling operation is seen as a continuous cyclic process having critical steps like - spotting dumper at loading point, manoeuvring the dumper, shovel loading time, hauling time with unloading and return, and the queuing time.[3]

It is noteworthy that the dumpers do not arrive at shovel uniformly and that the shovels do not load the overburden onto the dumpers at the same rate. This haphazard nature of arrival times of dumpers and the shovel service time for each dumper, results in either dumpers queuing at the shovel or the shovel being idle and waiting for a dumper to arrive.[4][5]

The concept of match factor is introduced to address the above mismatch in the shovel-dumper fleet.

$$\text{Match Factor} = \frac{\text{No. of Dumper} \times \text{Shovel Cycletime}}{\text{No. of Shovel} \times \text{Dumpercycletime}} \quad ....(1)$$

The above equation does not take into consideration the equipment capacities and specifications directly, however, they are integrally considered as factors which influence the cycle time of the HEMM.[6]

Match factor is not an indicator of the efficiency of the production process. It is used to gauge the efficiency of the selected combination of the fleet. A match factor of 1.0 indicates that the fleet is 100 % compatible with regard to the size and cycle time of the various shovels and dumpers. [6]

This paper discusses on the use of multiple linear regression to study the dependence of overburden removal on overall utilisation of HEMMs and optimising it using simplex algorithm to determine optimal level of overall utilisation and production at different match factors.

2. METHODS

2.1 Subject Issues

A 2.8 MTPA capacity opencast mine located in the eastern part of the country was chosen for the study. The annual target of overburden removal is 8.4 million m^3. The mine operates in 3 shifts a day. Particulars of operation of HEMMs are recorded and retrieved using fleet management system. For the purpose of the study, records of 92 consecutive shifts were collected. In table 1, specifications of the fleet deployed for removal of overburden are mentioned.

Table 1 Specification of HEMM for removal of overburden

HEMM	Capacity	Population
Rear End Dumper	95t, 60 m^3	18
Shovel	15 m^3	4

2.2 Parameters

In the mine a database is maintained to keep records of the shifts. Particulars of various components of the scheduled hours like running hours, maintenance hours, breakdown, trips in the shift are available for rear end dumper; likewise for shovel duration of running, face preparation, marching, breakdown, trips in the shift can be obtained.

Table 2 Particulars of direct parameters

HEMM	Direct Parameters	Mean ±σ	Max	Min
Rear End Dumper	Scheduled Hours	131.94±8.74	152	96.0
	Running Hours	55.95±10.34	92.1	30.6
	Maintenance	2.12 ±2.04	7	0.0
	Breakdown	35.02±11.74	57	2.25
Shovel	Scheduled Hours	32.0 ± 4.0	48	24.0
	Running Hours	16.31±2.89	23.4	11.2
	Marching	0.89 ±0.68	2.8	0.0
	Face Preparation	1.03± 0.72	3.25	0.0
	Breakdown	4.57 ±3.49	11	0.0
	Trips	175.78±41.09	270	72.0

Notes : σ- Standard deviation, Max. - Maximum, Min.-Minimum

2.3 Statistical analysis

In the study, T test is to check significance of the predictor variables and F test is to check overall adequacy of the model at 5% level of significance. Normal probability plot, residuals versus fitted value plot to ascertain residuals are seen normally distributed where variance of residuals is constant.

2.4 Formulation of models

In the multiple linear regression model, volume of overburden removed in a shift is the response variable which is estimated using predictor variables i.e. overall utilisation of dumper and shovel. The regression model has been developed using statistical analysis package MINITAB©.[7]

Using the regression equation as objective function in the linear programming with a view to maximise the function subject to constraints on overall utilisation of HEMMs for a predetermined value of match factor. The formulated linear programming model is optimised by simplex algorithm using the package TORA©.[8]

3. RESULTS

3.1 Linear regression model

From table 3, it is evident that the predictor variables are significant as p-value is less than the significance level. The variation inflation factor is close to 1 which indicates the variables are independent. The response variable i.e. volume of overburden removed per shift (V) related to the predictor variables by the regression equation is:

$$V = 1273.23 + 116.94X_1 + 98.69X_2 \quad \text{.....................(2)}$$

Where,

X_1: Overall Utilisation of Rear End Dumpers, X_2: Overall Utilisationof Shovels.

Table 3 Test of significance for the parameters of regression equation

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	1273.23	1379.61	0.92	0.359	
X_1	116.94	33.59	3.48	0.001	1.30
X_2	98.69	28.00	3.53	0.001	1.30

Notes : Coef- Coeffecient, SE Coef-Standard error of coefficient, VIF- Variance inflation factor

The adjusted coefficient of determination (adjusted R^2) is 0.3307.

In table 4, for ascertaining the overall adequacy of the model, hypothesis testing with significance level α= 5.0% has been carried out.

For regression equation of the formV= $\beta_0 + \beta_1 X_1 + \beta_2 X_2$, the null ($H_0$) and alternate hypothesis (H_a) for the coefficients of independent variables (β_j) are-

H_0: All β_j= 0, for j= {0, 1, 2}

H_a: At least one β_φ is different from zero, for j= {0, 1, 2}.

In table 4, P-value for all β_j, for j = {0, 1, 2} is less than α so the null hypothesis H_0 is rejected.

Table 4 F-test to check overall adequacy of the regression model

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	2	191049872	95524936	23.48	0.000
X_1	1	49303237	49303237	12.12	0.001
X_2	1	50558829	50558829	12.43	0.001
Error	89	362124876	4068819		
Total	91	553174748			

Notes : DF- Degrees of freedom, Adj SS- Adjusted sum of squares, Adj MS- Adjusted mean square

Fig.1 depicts the linear trend between response variable and predictor variables. However, such trend between predictor variables is absent.

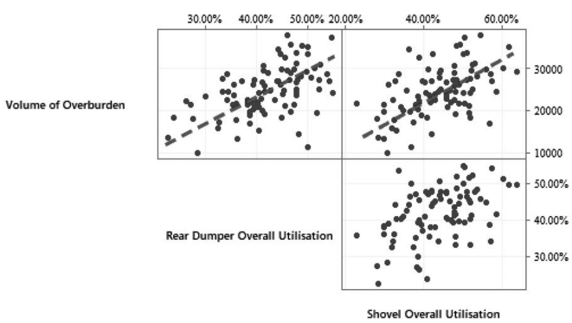

Figure 1 Scatter plot between response and predictor variables

From fig. 2 it is evident that most of the residuals are lying in a horizontal band; which indicates that variance is constant. The residuals are also normally distributed as depicted in fig. 3.

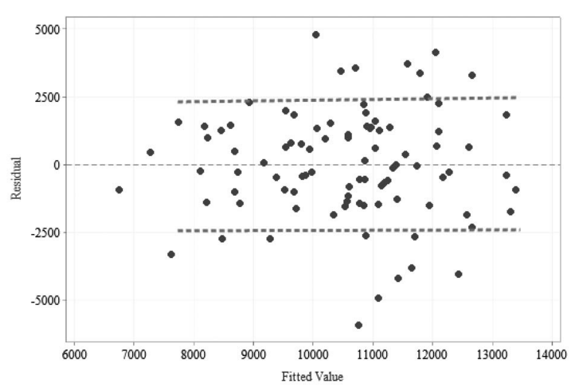

Figure 2 Plot of residual versus fitted value

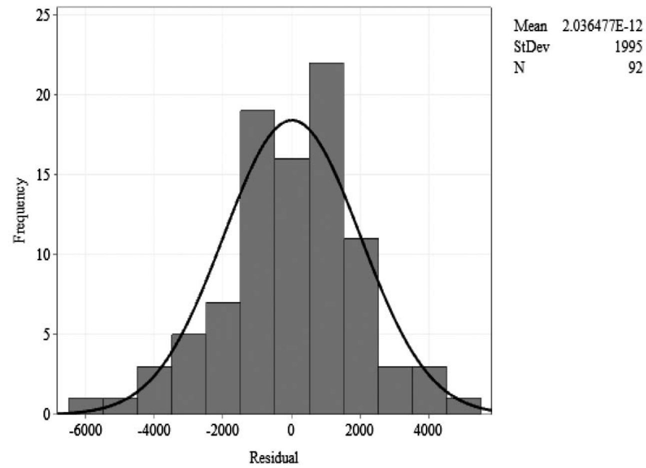

Figure 3 Distribution of residuals

3.2 Linear programming model

Linear programming is a mathematical modelling technique in which a linear function is to be optimised subject to the given constraints.

The objective function devised from the regression equation is as follows-

Maximise Z = $116.94X_1 + 98.69X_2$.... (3)

Subject to the constraints,

$X_1 \leq 67.72\%$ .... (i)

$X_1 \geq 22.78\%$ .... (ii)

$X_2 \leq 63.91\%$ .... (iii)

$X_2 \geq 22.82\%$ .... (iv)

$X_1 \times m_f - X_2 = 0$ .... (v)

$X_1, X_2 \geq 0$

Where,

X_1 : Overall Utilisation of Rear End Dumper

X_2 : Overall Utilisationof Shovel

m_f : Match Factor

Constraints (i), (ii) are upper limit and lower limit of overall utilisation for Rear Dumper; while (iii), (iv) are upper limit and lower limit of overall utilisation for Shovel. Constraint equation (v) relates to the overall utilisation of both HEMMs through match factor.

In table 5, the solutions of the linear programming model at mean match factor and at two standard deviations on either side of the mean are presented.

Table 5 Overall utilisation of HEMMs and production of overburden at different match factor

Match Factor	Optimal Overall Utilisation		Actual Overall Utilisation		Optimal Production of OB	Actual Production (% of Optimal Production)
	Rear End Dumper	Shovel	Rear End Dumper	Shovel	m^3	
0.64	68%	43%	44.93%	28.27%	13469.48	80.18%
0.84	68%	57%	43.61%	36.79%	14806.14	73.28%
1.06	60%	64%	50.47%	53.36%	14630.88	91.86%
1.27	50%	64%	39.04%	49.79%	13465.03	81.72%
1.48	43%	64%	32.87%	47.94%	12630.03	72.21%

4. DISCUSSIONS

The essential assumptions for a multiple linear regression model are:

i. Linear trend between response variables and predictor variables,
ii. Predictor variables should be independent,
iii. Residuals should follow normal distribution, and
iv. Variance of random error shall be constant [9] [10]

Adjusted $R^2 = 0.3307$ indicates the explanatory power of the regression model. Besides overall utilisation of loading and hauling equipment, several other factors like environment, geo-mining conditions affect production significantly. Consideration of influence of these parameters may lead to improvement of the explanatory power.

The linear programming model has been solved for mean value of match factor and two standard deviations out of it. In table 5, the optimal production possible is obtained for overall utilisation level at 68% for dumper, and 57% for shovel at match factor of 0.84. However, the maximum production has been achieved at the match factor of 1.06. Theoretically at ideal match i.e. match factor1 results in maximum productivity of the fleet.[6]. This is attributed to low level of actual overall utilisation of the HEMMs when compared to that of match factor 1.06.

The actual level of utilisation is significantly less than the optimal level. The effective working hours and overall utilisation drops due tothe factors shown in fig.4. Deterioration of haul road due to rain affect movement of dumpers along the haul road, absenteeism of operators make machines idle. Operations come to halt within the danger zone of blasting. Frequent breakdowns lowers availability of the machines. Congestion at affects maneuverability of dumpers at face. Higher lead distance increases cycle time.

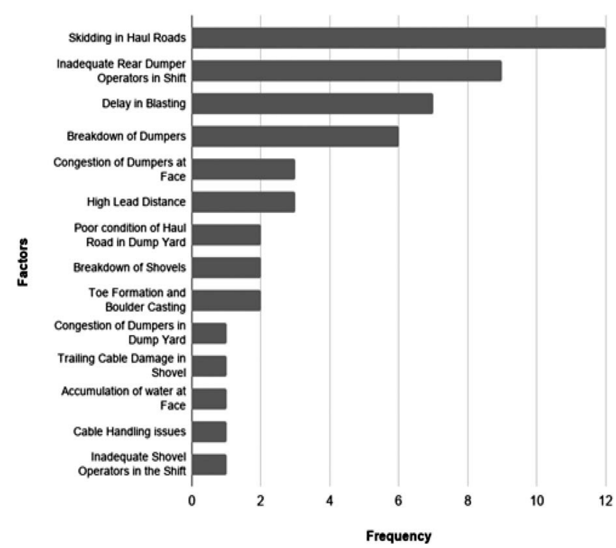

Figure 4 Factors affecting productivity of shovel and dumper combination

⏩ 5. CONCLUSION

From the study it is concluded that in the opencast mine proper utilisation of HEMMs, matching of the fleet are vital aspects for carrying out the scheduled operations. The mean match factor 1.06 is close to the recommended value 1 from the perspective of productivity and any deviation affect the production in a shift significantly. Adequate measures to improve effective working hours can lead to better utilisation of the machines. Inclusion of environmental factors, condition of haul roads, and agility of maintenance teamwith behavioural aspects of operators in the models will improve estimates of optimal overall utilisation of HEMMs. This can be taken up in further studies.

⏩ Acknowledgment

We intend to show our gratitude to the academic and administrative authority of Indian Institute of Engineering Science and Technology, Shibpur, West Bengal, India.

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DESIGN OF WIDE STALL METHOD OF PILLAR EXTRACTION USING CONTINUOUS MINER IN A PANEL LYING BELOW DAGDOWA VILLAGE: A CASE STUDY

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Abstract :

A number of coal seams in India are lying at shallow depth of cover below surface or subsurface structures like railway lines, roads, buildings, villages/ residential colonies, pipelines etc. It is difficult to mine such coal seams and are left standing. It is locking considerable reserves of coal due to the establishments/civilization/structures on the surface over it. Sometimes, it is difficult to shift people living above the coal seam due to different politico-economic reasons. There is a need to choose a judicious mining method among the available techniques which does not cause any subsidence on the surface and damage to the surface/subsurface structures. Previously, such deposits below surface structures have been extracted judiciously using different partial extraction methods with drilling and blasting but strength of the pillar gets diluted during the judicious extraction as the pillar size gets reduced. Mechanised extraction using continuous miner and bolting with fast setting resin capsules as roof support technology has enabled to maintain a wider span of gallery and extract coal seams judiciously lying below surface structures. It results into an improved and stable exposed coal pillar surface and support system to the roof. Estimation of factor of safety helps in evaluating the long-term stability of these reduced size of coal pillars during wide stall method. CMRI pillar strength formula is used to estimate the strength of the reduced size of coal pillars. Previous studies revealed that FOS equal to or more than 2.0 is long-term stable and do not cause any damage or subsidence to the surface/ subsurface structures. Also, numerical models in FLAC^{3D} are used for the support design for widened galleries during the judicious reduction of pillar.Discussing the site conditions of 34LW panel lying below Dagdowa village, this paper describes the design of different involves structures for judicious extraction of locked-up coal pillars by continuous miner technology with ram car based on empirical, field and numerical studies. Wide stall method is found to be suitable for final partial extraction of pillars in the 34LW panel lying below Dagdowa village using continuous miner technology which do not cause any

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subsidence on the surface. Simulation study is done to design the safe span of stall (widened gallery) for the geo-mining condition of the panel, which is found to be 6.0 m.

Keywords : Wide stall method, Pillar, Gallery, Bolts, Safety factor, Long-term stability, Continuous miner, Support system.

1. Introduction

Coal has been the prime source of energy in India since long back. It has been also utilized by many industries and domestic purposes in the country. Even after exploration of alternative source of energy generation, coal is still a major source of energy. It accounts for 55% of the energy need of the country. Indian coal industry has developed most of the coal seam by conventional Bord and Pillar Mining Method (BPMM) to meet the demand of coal in the beginning. In fact, this operation of coal mining requires low capital investment and low level of engineering support. The instability problem of underground structures formed during development by this method is also almost negligible. However, the recovery of coal during development is comparatively less and found to be in the range of 20 to 30%. This approach of coal production has locked large amount of coal in these pillars (Dixit and Mishra, 2010). On the other hand, the demand of coal is increasing at a considerable rate with time. Now, the industry is looking for extraction of coal which is locked-up in developed pillars and exploring different technology and methodology for its final extraction (depillaring). Semi-mechanised and mechanised depillaring methods with caving (Singh 2004; Singh et al. 2008, Singh et al. 2016, Ram et al. 2017 Kumar et al. 2018, Kumar et al. 2020) are generally used for extraction of these developed pillars. In this method, the surface as well as sub-surface features lying above the panels were allowed to damage/disturb. But, in case of presence of important surface/sub-surface features above the developed panels, this method cannot be adopted. Under such circumstances, only those extraction methodologies can be used, which would not create any damages/disturbances of the important surface/sub-surface features. A panel of L-1B seam at Vindhya mine has the similar condition, which is partly developed on pillars and partly virgin lying below a village, which could not be shifted (CSIR-CIMFR Report 2020). Further, extraction of coal below should be planned in such a manner that it should not damage any village structures above it. In this paper, details of different possible method of mining for existing geo-mining conditions of the panel including suggestion of suitable mining approach with proper support system and related strata control issues are discussed and analysed in the subsequent sections.

2. Site Details

Vindhya Mine of M/s South Eastern Coalfields Limited (SECL) has two workable coal seams, namely, Johilla Top and L-1B seam (CSIR-CIMFR Report 2020). The coal seams of this mine are of Lower Permian stage and occur in Barakar formations. The strata are dipping towards north in western and central part, whereas in the north-eastern side, it is towards NE-NW. Both Johilla Top and L-1B seam are developed on pillars and galleries by BPMM. L-1B seam is being extracted by mechanised depillaring with caving using continuous miner and ram car with gallery width of 6.5m (Kumar et al. 2018). Thickness of L-1B seam varies from 2.08 to 3.27 m with an average gradient of 1 in 13. Roof bolts has been used for supporting boththe galleries and goaf edges during its depillaring. The 34LW panel of same seam is situated below Dagdowa village. Major part of the panel is developed along the floor to an average height of 2.8 m and rest is virgin (Fig. 1). Geo-mining details of the panel are given in Table 1.

Table 1 Brief geo-mining parameters of the 34LW panel.

Particulars	Descriptions
Thickness of the seam	2.08 to 3.27m
Gradient of the seam	1 in 13
RMR of the seam	46.9
Pillar size (centre to centre)	Maximum 25m × 25m and minimum 25m × 20m
Average width of the gallery	4.2m
Average height of extraction	2.8m
Depth of cover	85-115m
Nature of roof and floor	Roof : Carbonaceous shale, coal (L1Aseam), sandstone Floor : Sandstone, coal

The panel is to be extracted by a suitable partial extraction method. During the field investigations, it was found that the roof and pillars of the panel were almost intact, but galleries were widened to 5.0m at few places from its original width of 4.2m due to time dependent failure of pillars as the panel was developed long back. No local roof fall was noticed in the panel, but, some geological features like faults, slips/joints are found at few places in the panel during the investigation. A fault is situated in the middle of the panel which is extending along nearly north-east direction and terminating in the panel itself. In the northern and dip side of barrier pillar of the panel, another fault with throw of 110m is passing nearly along east-west direction (Fig. 1).

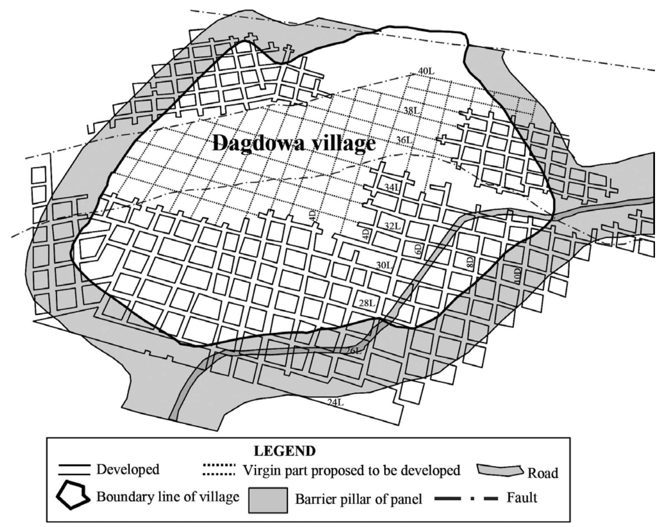
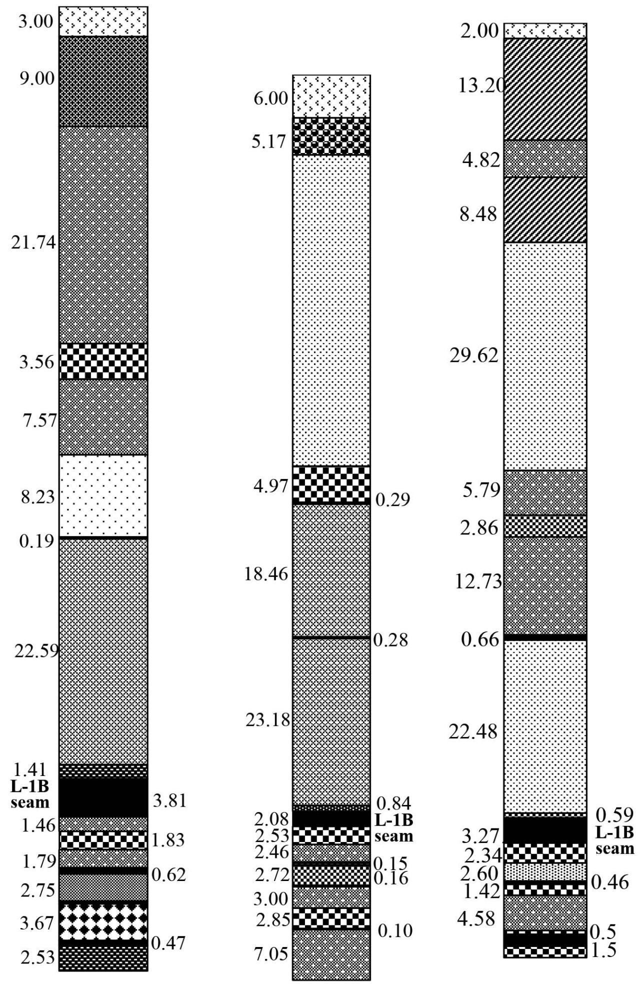


Fig. 1. Working status of the 34LW panel of L-1B seam at Vindhya mine.

⏩ 3. Characteristics of Roof Rock Mass

Some panels of the seam were already depillared with caving by mechanised depillaring method in association with CSIR-CIMFR (Singh et al. 2016, Ram et al. 2017, Kumar et al. 2018). The nature and behavior of the overlying strata is found to be easily caveable in nature with RMR 47. The roof strata over the 34LW panel are found to be almost matching with that of the previous depillared panels of seam having caveability index of around 2100 only which comes under easily caveable strata (Kumar et al. 2018, Singh et al. 2020, Singh et al. 20201). The sections of different overlying and underlying strata formations of seam, obtained through Borehole No. JP-21, JP-63 and JP-174 (located within the panel), is shown inFig. 2. It shows that the overlying formations are, mainly, consists of sandstone and the immediate roof of L-1B seam is carbonaceous shale, which needs to be dealt carefully while working in the panel.



Borehole No. : JP-21 Borehole No. : JP-63 Borehole No. : JP-174

Note: All dimensions are in meters

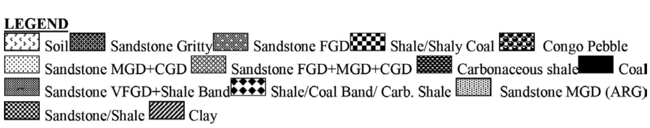


Fig. 2. Section of overlying and underlying formation of L-1B seam.

⏩ 4. Possible Methods of Mining

Partial extraction and full extraction with stowing are found to be the two suitable options for its mechanised depillaring, but sand or other materials required for stowing is not available in the mine. Under such condition, only partial extraction method is left as an option for mechanised depillaring. In partial extraction methods, the width of the excavation is kept less than Non-Effective Width (NEW) (Saxena et al. 1989, Sheorey & Singh 1996, Sheorey and Loui 2002) which provides zero deformation/subsidence on the surface/subsurface. A brief review of the following available partial extraction methods reveals the limitations and scopes of these options for panel extraction.

⏩ 4.1. Limited span (narrow panel mining) method

Alternate row of pillars is extracted in this method (Saxena et al. 1989, Sheorey & Singh 1996, Sheorey and Loui 2002) by driving width of gallery lying in the range of NEW, leaving sufficiently strong solid remnants of coal pillars and stable roof for restricting strata movement and consequent damage to the overlying strata, surface and subsurface features. The geo-mining condition of the panel restricts the size of void for optimisation of coal recovery from the standing pillars. For successful implementation of this method, it must satisfy the following conditions.

i) NEW = W_V / H
 where, W_V = width of void span, in m and H= depth of cover, m

ii) Safety factor (SF) of the remnant pillars (pillars between the void span) must be more than 2.0 (Sheorey 1993).

SF = Load on the pillar / Strength of pillar

Load on the pillar (P) left in between void span is estimated by using following Wilson's formula :

a) $L_p \geq 2fH$

$$P = \frac{0.025H\left[(W + fH)(W + B)\right]}{W^2}\ \text{MPa} \quad (1)$$

b) $L_p \leq 2fH$

$$P = \frac{0.025H\left[(W + L_p)H - \frac{L_p^2}{4f}\right](W + B)}{W^2}\ \text{MPa} \quad (2)$$

where, L_p= panel width (width of void and two adjacent solid pillar) (m), W = pillar width (corner to corner) (m), H = depth of cover (m), B = width of gallery (m), f = 0.3 for caving and 0.2 for stowing.

CSIR-CIMFR has developed an empirical relationship for estimation of pillar strength (S) after considering the large number of failed and stable cases at different sites in terms of different geo-mining parameters of a coal pillar (Sheorey et al. 1987, Sheorey 1992), which is given as below:

$$S = 0.27\sigma_c h^{-0.36} + \left(\frac{H}{250}+1\right)\left(\frac{W_e}{h}-1\right) \text{ MPa} \quad (3)$$

where, S is pillar strength in MPa, σ_c is uniaxial compressive strength of coal in MPa, h is working height in meter, H is depth of cover in meter, w_1 is length of the pillar (corner to corner) in meter, w_2 is width of the pillar (corner to corner) in meter, effective pillar width (w_e) = 4A/P_c, area of pillar (A) = w_1w_2 and perimeter of the pillar (P_c) = 2(w_1+ w_2).

The value of NEW is determined by using CSIR-CIMFR formula with the help of thickness and type of overlying formation (Saxena et al, 1989) of L-1B seam obtained through Borehole No. JP-21, JP-63 and JP-174 (lying within the panel). The estimated values of NEW from Borehole No. JP-21, JP-63 and JP-174 comes to be 0.27, 0.23 and 0.22 respectively and its average value is 0.24. For the condition of the panel, the span of void created after taking alternate row of pillars (maximum size) is 29.2 m. NEW value of the seam is 0.24, which allows maximum void span of 27.6 m only for maximum depth of 115 m. Also, safety factor of the left-out pillar is found to be 1.64, which is less than 2. Therefore, both, estimated width of the void and safety factor of left out pillar did not support the application of this mining method in the panel.

⏩ 4.2. Chess board method

In this method (Saxena et al. 1989, Sheorey & Singh 1996, Sheorey and Loui 2002) every alternate pillar in each row is extracted in Chess board pattern. The goaf area formed in this pattern of extraction is equal to product of (W_1+B) and (W_2+B), where W_1 and W_2 are centre-to-centre length and width of pillar respectively. For the successful implementation of this method, the condition is (W_1 +B) ≤ 1.25(H)(NEW) and the safety factor of the left-out pillars should be at least 2.

For the condition of the panel the estimated safety factor of the left-out pillar is 1.64, which is not suitable for this method. However, the overall span created after extraction of alternate pillar by this method is 29.2m (taking maximum pillar size = 25m × 25m and gallery width = 4.2m) which is less than required value of 34.5 m i.e., 1.25 (NEW) (H). Therefore, this method cannot apply for the partial extraction of coal pillarsin the panel.

⏩ 4.3. Splitting and stooking method

In this method (Saxena et al. 1989, Sheorey & Singh 1996, Sheorey and Loui 2002), the pillars are first divided into two equal parts by driving one level split galleries and thereafter the split pillars are divided into two equal parts (stooks) by driving dip-rise galleries. The width of level split and dip-rise galleries are generally kept equal to width of the original galleries. This method can be used if the stooks formed during this process of pillar extraction are stable for long-termwith safety factor more than 2. The safety factor of the stooks is estimated through determination of its strength using equation 3 and the load on the pillar by Tributary area method (Poulsen 2010), which is given as below:

$$P = \gamma H \frac{(W_e + B)}{W_e} \text{ MPa} \quad (4)$$

where, γ = Unit rock pressure, which is generally taken as 0.025 MPa/m for Indian mining conditions.

The estimated safety factor of stooks for the condition of the panel comes in the range of 0.98 and 1.30, which is not long-term stable, therefore, this method not suitable forpartial extraction of coal pillars below village. Also, the general stress distribution pattern over a stook revealed high stress concentration on the sides and the whole stook subjected to induced stress (Singh & Singh 1999). High skin stress is likely to induce side spalling, time dependent faster decay and overall instability of the stooks. Crushing/failure of a stook may change the stress redistribution pattern in and around the workings creating destabilisation problem for surrounding stooks/pillars and overlying strata. Spalling of the coal pillar, results in reduction of ultimate stook size, which wasalso unfavourable for mechanised depillaringwith conventional splitting and stooking.

4.4. Wide stall method

Wide stall method (Singh and Singh 1999, Singh et al. 2008) involves the extraction of pillars by widening of galleries either in L-shape or from all sides of the pillars leaving sufficiently strong solid remnant coal pillars. The widening of the existing galleries from all sides of the pillar is generally preferred due to removal of the weathered (time dependent) coal surface around the pillars. This removal also provides intact freshly exposed surfaces along the galleries. It is generally preferred for coal seams situated at moderate depth of cover and overlying strata must have more than 20m hard cover to prevent the chances of pot holing (Singh et al. 2008). Almost same recovery of coal is obtained in this method as in splitting and stooking method, but it provides relatively, stronger natural support in form of left-out pillar core for overlying structure. The application of this method depends on the long-term stability conditions of the designed stall span (width of widened roof) and remnant pillar, which can restrict any damage to the surface/sub-surface features lying above the panel. The safety factor of the designed remnant pillars should be more than 2.0 forlong-term stability of underground structures. Detailed studies of these parameters to decide the suitability of this method for the conditions of the panel is described below:

4.4.1. Stall span design

The stability of mine roof or stall span is dependent on the competency of the immediate roof. In the panel, the overlying roof formation of the seam consists, mainly, sandstone (Fig. 2) (RMR 47 and depth 85-115m), which is competent enough to arrest the collapse of rock mass column over the stall. Here, it is also to be noted that pillars being extracted by continuous miner and ram car, needs a gallery width more than 5.0m and generally, resin grouted roof bolts of 1.8m length are used to support the roof of the galleries. In case of using roof bolts of 1.8 m length, the maximum allowable height of the affected roof due to mining is estimated as 1.2m considering 1.5 safety factor. Simulation study is done initially for gallery width of 5.0 m and then widened up to 6.6 m. For each gallery width, the height of affected roof is recorded in the numerical models. Details of simulation study is discussed in the subsequent section.

4.4.2. Numerical simulation

Simulation studies has been carried out for the condition of the panel using FLAC^{3D} (Itasca 2012) to study the variation in roof deformation for different widths of the galleries. The real conditions of the site are simplified for the finite difference modeling and a symmetric development condition of the panel with four pillars

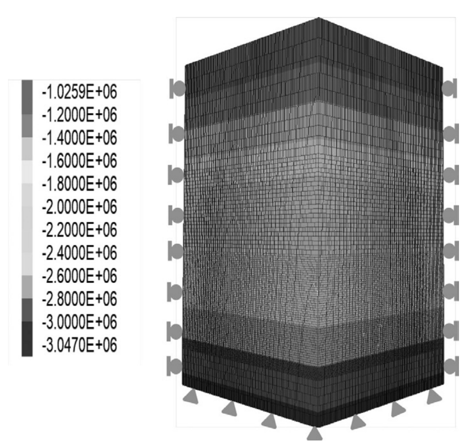


Fig. 3 is taken for modelling (Singh et al. 2016, Kumar et al. 2018, Kumar et al. 2019a, Kumar et

al. 2019b). A model with 45.8 m length and 45.8 m width is generated as per the laboratory tested and available material properties (Table 2) using following equation 5 and 6.

$$K = \frac{E}{3(1-2v)} \qquad (5)$$

$$G = \frac{E}{2(1+v)} \qquad (6)$$

where, E = Young's modulus in GPa, K = Bulk modulus in GPa, G = Shear modulus in GPa and v = Poisson's ratio.

The value of the compressive strength σ_c is estimated through laboratory testing. Tensile strength is simply taken as one tenth of compressive strength for coal measure rock and one tenth for coal (Sheorey 1997). *In situ* stress values for modelling is estimated as per Sheorey (1994) and Sheorey et al. (2001), which are given as:

$$\sigma_v = 0.025H \qquad (7)$$

$$\sigma_H = \sigma_h = 2.4 + 0.01H \qquad (8)$$

where, σ_v = vertical *in situ* stress in MPa, σ_H = major horizontal *in situ* stress in MPa, σ_h = minor horizontal *in situ* stress in MPa and H is depth of cover in meters.

Dimensional information is kept similar to that of the actual length and width of the pillars with extraction height of 2.8m and depth cover of 115m. Considering memory, runtime constraints, the simulation is done up to a height of 76m from the coal roof and 10m from the floor. Normal mesh generation is done at 0.32m grid pattern in direction of x and y axis, but the vertical meshing is done at an interval of 0.2m for coal seam, 0.5m for shale and immediate roof up to 24m height from coal seam. A truncated load (0.025 x depth of cover, MPa) for the unmodelled portion of the overlying strata is applied over the model. The sides and bottom boundaries of the model are fixed in horizontal and vertical direction and the top one is kept free. After executing this virgin (*in situ*) model to the equilibrium (Fig. 3), galleries of considered width are developed in stages and each stage of excavation is executed up to the equilibrium. Width of gallery is taken initially 5.0m and then it is increased to 6.6 m. The size of the remnant pillar is varied with change in the gallery width. Developed models for different pillar and gallery widths are run to the equilibrium and CMRI (now CSIR-CIMFR) safety factor is applied in $FLAC^{3D}$ using FISH to study the height of affected roof due to drivages of different widths of gallery. The height of the affected roof for 6.6 m width is recorded to be 1.2 m(Fig. 4). As mentioned above that the allowable height of affected roof for the condition of the panel is 1.2m. Thus, this modeling is done up to the gallery width for which the height of affected roof attains 1.2m or less. It is found that for a maximum of 6.6 m gallery width, the height of the affected roof is observed to be 1.2m which is suitable for application of this method in the panel. However, considering the long-term stability of the ground surface of village, safe and optimal coal extraction from the pillars, 6.0m gallery width is proposed for application of wide and stall method of pillar extraction in the panel.

Table 2 Material properties used in numerical modeling.

Material	Thickness (m)	Young's modulus (GPa)	Poisson's ratio	Bulk modulus (GPa)	Shear modulus (GPa)	Density (kg/m^3)	RMR	UCS (MPa)
Floor (fine grain sandstone)	10	7.0	0.25	4.67	2.80	2400	70	60
Coal	3	2.0	0.25	1.34	0.80	1400	30	20

Material	Thickness (m)	Young's modulus (GPa)	Poisson's ratio	Bulk modulus (GPa)	Shear modulus (GPa)	Density (kg/m³)	RMR	UCS (MPa)
Carbonaceous shale	0.5	3.0	0.25	2.00	1.20	2250	30	25
Medium grainsandstone	22.5	6.0	0.25	4.00	2.40	2400	55	40
Johila bottom seam	1.0	2.0	0.25	1.34	0.80	1400	30	20
Fine plus medium grain sandstone	13.0	7.0	0.25	4.67	2.80	2600	60	40
Shale	3.0	3.0	0.25	2.00	1.20	2250	30	30
Fine grained sandstone	6.0	7.0	0.25	4.67	2.80	2600	60	40
Roof (Medium grain sandstone)	30.0	6.0	0.25	4.00	2.40	2400	50	35

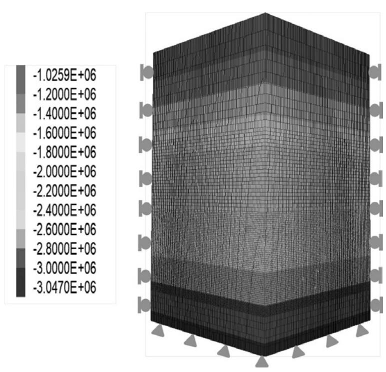


Fig. 3. Vertical stress distribution and boundary conditions in *in-situ* model during numerical modelling in FLAC^{3D}.

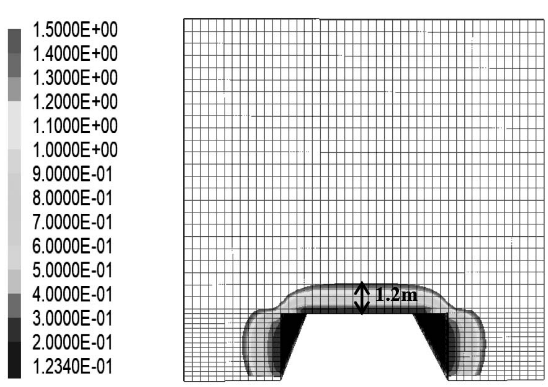


Fig. 4. Safety factor contour showing the rock load height to be supported for gallery width of 6.6 m.

4.4.3. Pillar design (pillars after widening of the galleries)

For the existing condition of the panel, the maximum and minimum size of the remnant pillarsafter widening of the galleries to 6msize becomes 19m × 19m and 19m × 14m respectively. Taking the maximum depth cover of 115m, safety factor of left-out pillars is determined using above formula and found to be 2.7 and 2.2 respectively which is suitable for long-term stability point of view.

4.4.4. Width to depth ratio of the working and possibility of pot-holing

Pot-hole occurs due to shallow depth cover, large dimension of drivages, weak and unconsolidated overburden and geological discontinuities. Water seepage, rain fall and earthquake aggravate the occurrences of pot-holes. Till date, there is no reported case of pot-hole for the existing depth range of the panel. The proposed wide stalling in the panel consists of maximum 6m width of the extracted strip which is to be followed by pillars having w/h ratio of 6.8 (width to height ratio of the pillar) and their safety factor is varying in between 2.2 to 2.7. For 6m wide void, the width to depth ratio is only 0.05, which is less than existing NEW of 0.24, which eliminates the chances of any interaction between the two workings. The overlying rock mass of the designed stalls are also competent (Fig. 2). Based on these facts, it may be concluded that the possibility of pot holing during application of wide stall method in the panel is remote.

5. Method of working

Considering the applicability of the different partial extraction method for the existing geo-mining conditions of the panel as discussed above, it is decided to adopt wide stall method for extraction of coal from the panel. In the developed part of the panel, the existing gallery is widened to 6m by taking coal from all sides of the pillars (Fig. 5) using continuous miner and ram car. The virgin part of the panel is freshly developed to gallery width and height of 6.0 m and 2.8 m respectively using same continuous miner and ram car. The percentage of extraction is varied from 42 to 47% including that of the initial development.

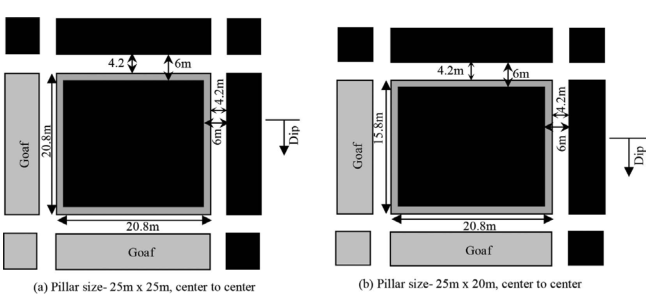


Fig. 5. Widening of galleries from all sides of pillarin the panel

6. Support system for widened galleries and junctions

The existing developed galleries and junctions of the panel are already supported with three numbers of full column cement grouted roof boltsof 1.5m length at 1.2m and 1.0m grid pattern respectively. During widening operation of this part of the panel lying below village, four additional full column resin grouted roof bolts of 1.8m length are fixed in a row between the existing roof bolts at 1.5m grid pattern. At junctions of this part, five additional roof bolts of same length are fixed in a row at 1.2m grid pattern in between the existing roof bolts. In freshly widened galleries (6m wide) in virgin part of the panel, five full column resin grouted roof bolts of 1.8m length are installed in a row at 1.2m grid pattern. The widened junctions of this part are supported by six full column resin grouted roof bolts of same length in a row at 1.0m grid pattern. The widened junctions of both parts are also supported by four additional cross-stitching in conjunction with eight numbers of resin grouted eye-bolts of 1.8m length. At geologically disturbed places, roof bolts with w-straps are fixed to eliminate the possibility of any instability problem. The adopted support system in the widened galleries and junctions in both parts of panel is shown inFig. 6 and Fig. 7.

6.1. Support safety factor

The effectiveness of the adopted support system in both parts of the panel is assessed through determination of the Support Safety Factor (SSF) using following relation:

$$SSF = \frac{\text{Support Resistance}}{\text{Rock load}} \qquad (9)$$

Airey (Wilson, 1983) made a mathematical study for estimation of rock load to be experienced in the roof after drivage of gallery. It stated that the strata buckled after drivage of gallery with an angle of break to the vertical in stratified rock, which is almost same as the angle of internal friction (ϕ). The developed equation by Airey for estimation of rock load in the gallery is given as:

$$\text{Rock load (Pr)} = \left[\frac{B}{4\tan\phi}\right]\gamma \qquad (10)$$

where, B is width of the widened gallery, γ is dry unit weight of roof rock and ϕ is angle of internal friction.

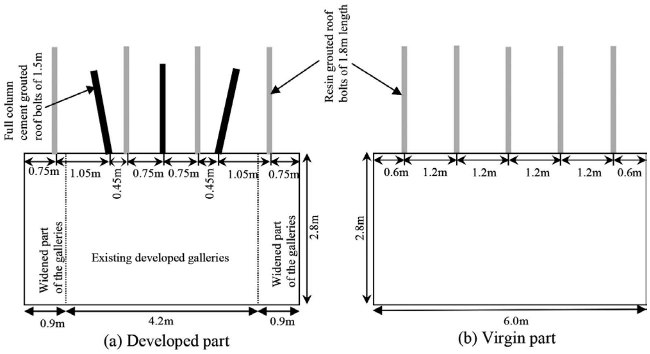


Fig. 6. Support system adopted in the widened galleriesof both parts in the panel.

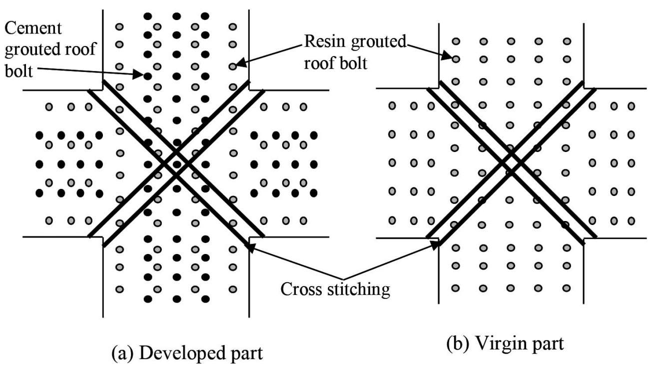


Fig. 7. Support system adopted in the widened junction of both parts in the panel.

The dry unit weight of roof rock in the panel is 2.04 t/m^3 and the average value of ϕ for stratified roof is 45^0. Rock load for 6m wide galleries of the panel is determined using above equation which comes to be 3.06 t/m^2. At junctions, it is generally taken as 1.5 times that of the gallery i.e., 4.59 t/m^2. To assess the anchorage strength of both existing cements grouted and freshly installed resin grouted roof bolt in the panel, the anchorage testing of these bolts is done, which comes to be 5 t and 20t respectively. The anchorage capacity of rope, used for cross-stitching, is tested in the laboratory which comes to be 6 t. Support Resistance (SR) is calculated by using following formula:

$$SR = \frac{\text{Support density}}{\text{Area supported by one row of support system}} \quad (11)$$

The calculated load resisted by adopted support system in widened galleries and junction of both parts of panel is 13.89 t/m^2 and 21.57 t/m^2 respectively. Thus, the estimated value of SSF in the widened galleries and junction comes to be 4.5 and 4.7, which is suitable for its long-term stability.

7. Measurement of Strata Movement Through Instrumentation

Behaviour of strata during widening of galleries in both parts of the panel is studied through instrumentation and monitoring to visualize the performance of different elements of designed methodology. It provides some quantitative figures of strata movement in and around the workings for better understanding of the rock mass behavior. In the adopted methodology, strata movement around the workings especially; movement of the roof in the widened galleries is a prime concern for safe and efficient extraction of the panel. Considering this fact, roof dilation/ deformation is measured using Single Height Tell Tales (SHTT) and Auto Warning Tell Tales (AWTT) during widening operation in the panel. Considering the roof characteristics of the widened gallery, it is proposed to use SHTT, which is fixed at a height of 3.5m in the roof in middle of each dip-rise and level galleries and AWTT is at same height in the roof of each junction. AWTT starts flashing automatically after attaining the fixed/set values of 5mm roof movement in the instrument within 3.5m roof horizon. No flashing of AWTT is noticed during widening operation of the panel, which indicated that strata movement within 3.5m roof horizon remains below 5mm. In SHTT, maximum recorded roof deformation during widening operation in the panel is only 2mm.

8. Conclusions and Recommendations

Wide stall method is found to be suitable for final partial extraction of pillars in the 34LW panel lying below Dagdowa village using continuous miner technology which do not cause any subsidence on the surface. Further, continuous miner based mechanised mining technology added to the long-term stability of both roof of widened galleries and left out pillars due to cutting of coal pillar by machine. In fact, drilling and blasting operation in conventional mining creates fracture in both roof and pillar to a certain depth, which creates loose rock and causes the instability of surrounding rock mass of the working face. In this method, proper design of stall span and remnant pillar is required for safe and efficient extraction of the panel. Simulation study is done to design the safe span of stall (widened gallery) for the geo-mining condition, which is found to be 6m. Also, for 6m wide gallery, the safety factor of the left-out pillar in the panel comes in the range of 2.2 to 2.7, which is suitable for long-term stability the underground workings. The overall recovery (including initial development) in the panel for this gallery width comes in the range of 42 to 47%. Strata movement in the roof is also measured in the panel during its widening using both SHTTs and AWTTs. It is found that the roof sagging in the panel is observed to be below 2mm, which is under safe condition.

Acknowledgement

The authors are obliged to the Director of CSIR-CIMFR, Director of IIT (ISM), Director of NIT Rourkela and Vice Chancellor of Kazi Nazrul University for their permission to publish this paper. The results of this paper are partially based on one industry sponsored projects funded by the South Eastern Coalfields Limited (SECL). Thanks are due to the management of Vindhya mine and SMSL for their valuable co-operation during the field observation. The views expressed in this paper are those of the authors and not necessarily of the Institute to which they belong.

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EXPERIMENTAL STUDY TO RATIONALLY REDUCE BLAST-INDUCED GROUND VIBRATION AND AIR OVERPRESSURE

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Abstract :

Attention towards blast-induced ground vibration and air overpressure has been increased in recent times due to increased settlements near mines. The blast-induced ground vibration and air overpressure generally depends on maximum charge per delay that is detonated at any particular time. Trial blasts have been conducted using distributed spherical air-gap (DAG) blasting technique, air-deck technique, plastic bottle technique and plastic tube technique in order to reduce maximum charge per delay when compared to conventional blasting. The PPV (peak particle velocity) and air overpressure values are measured for all the trial blasts and are compared with the PPV and air overpressure values of conventional blast practice. All the techniques for explosive consumption reduction have significantly reduced ground vibration and air overpressure levels than conventional blasting technique.

Keywords : Ground vibration, Air overpressure

Introduction

The blast-induced ground vibration and air overpressure can cause damage to the structures surrounding the mining locality. In recent times the ground vibration and air overpressure are drawing more and more attention due to increased human settlements near the mine. Study of the characteristics of ground motion and air overpressure involves various complexities. Various studies have been performed to predict, control and understand the factors affecting blast-induced ground vibration and air overpressure (Clay and Huag,2000; Agrawal and Mishra, 2019; Afrasiabian et al. 2020; Aldas, 2010; Amiri et al., 2020).

Frequency of the blast wave, peak particle velocity (PPV), displacement and acceleration of the particles are important parameters associated with ground vibration. Among these parameters, PPV is considered as the most important criterion to study the structural damage (IS 6922, 1973; Kumar et al., 2016). The noise level generated by the blast is used to characterize the air overpressure. The intensity and nature of blast-induced ground vibration and air overpressure depends on a number of factors (Singh et al., 1994; Bhandari, 1997). The factors can be parted in controllable and uncontrollable groups. The type and amount of explosive used, blast geometry, priming, scattering in delays, and initiation are

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controllable parameters. The geological conditions, distance from the face, meteorological conditions come under the uncontrollable parameters.

The amplitude of pressure pulse is directly proportional to the amount of explosive used. As the holes are delayed, the explosive detonated at one time becomes more important than total explosive detonated in the blast. Charge per delay is the most important factor controlling the intensity of ground vibrations. A larger quantity of charge per delay results in higher vibration and air overpressure levels. Wiss and Linehan (1978) found that the use of large diameter holes will produce increased ground vibration than smaller diameter blast holes due to increased charge per meter. The explosives which produce more gaseous energy than shock energy are more likely to cause ejection of gases and thereby producing high amplitude air overpressure. Similarly, the lower density explosives are also more likely to generate a lower intensity of ground vibrations than higher density explosives (Bhandari, 1997).

The blast geometry affects ground vibration and air overpressure levels. Excessive burden increases the ground vibration because the explosive energy is insufficient to break the burden. Similarly, if the burden is less than optimum then the gaseous energy will be dissipated into the atmosphere without doing useful work thereby causing flyrock and air blast. The early release of gases generates air overpressure of reduce magnitude. Front row holes with small burden pose problems of air blast in high and inclined faces. Strong air overpressure can be produced by the adjacent movement of a face during the blast if the spacing between holes is less than the distance travelled by a sound wave during the delay time between adjacent-blast hole detonations. The subgrade portion also creates a zone of extra explosive energy which causes ground vibration.

Smaller stemming columns are more likely to generate higher ground vibration. The air overpressure levels also increase due to insufficient stemming. The delay also affects ground vibration and air overpressure levels. The delay provides separate wave fronts emanating from the corresponding charges thus avoiding the superimposition of blast waves. The ground vibration levels can increase if the front row burden cannot move forward to provide enough free face to the next subsequent row. Wiss and Linehan (1978) concluded that the pulse generated from two different charges travel independently if the delay provided is more than 8 ms. Dick et al. (1983) recommended 8-9 ms as a minimum delay that can be used between charges if they are to consider as separate charges for vibration purpose. Hagan and Kennedy (1977) found that bottom initiation usually gives less noise and air blast but slightly higher ground vibration levels. The detonation cords are also a source of the high-frequency pressure pulse in surface mine blasting.

The lithology of the rock mass strongly influences the ground vibration. The strength, density, and porosity of the rock also affect the blast wave propagation. Harder rock has more frequency whereas, blast vibrations are more intense in loose soil (Bollinger, 1971). The direction of propagation of the blast wave is changed by the presence of discontinuity and the nature of filling material. The burden rock which is highly jointed or contains a weak zone generates more air overpressure as the gases tend to escape from these zones. The presence of joints, fractures, faults, and shear zones in the path of a ground motion wave also act to scatter the peak vibrations (Bhandari, 1997). The air overpressure transmits through the atmosphere. Hence, the meteorological conditions such as wind speed and direction, temperature, cloud cover, and humidity will also affect the intensity of air overpressure.

For the purpose of this research, trials have been conducted using distributed spherical air-gap (DAG) blasting technique, air-deck technique, plastic bottle technique and plastic tube technique thereby reducing maximum charge per delay. The PPV and air overpressure values are measured for all the trial blasts and are compared with the PPV and air overpressure values of conventional blast practice.

Site of study

The study has been conducted at Century Cement limestone mine which is a captive mine of M/s Century Cement. It has an integrated cement plant at Baikunth in Raipur district of Chhattisgarh, India. It is located at about 50 km from Raipur. The mine is having total mining lease area of 311.846 ha. The total lease area is divided into three blocks namely; block 'B', block 'MF2'and block 'G'. Block 'G' is not operational at present. The quarry produces cement grade limestone with $CaCO_3$ varies from 70-76% and SiO_2 ranges from 5-12%.

In each of the blocks, besides the overburden bench, there are three benches of varying height. The height of benches varies from 6.0-9.5 m. Excavation of the limestone is done by conventional drilling and blasting using site mixed emulsion explosive. The blast holes are drilled by using diesel operated Intersolland IBH-10 and BVB-25 rotary percussive drill machine capable of drilling 115 mm diameter holes. The blasted muck is removed by using 3.2 m^3 and 4.6 m^3 hydraulic shovels and 35 t dumpers. The dumpers carrying muck are weighed at the pit head. The dumpers unload their content in the crusher. The maximum feed size of the crusher is 800 mm. For secondary breakage, rock breaker is used.

Experimentation

Five trial blasts using conventional blast practice, DAG blasting technique, Air-deck technique, plastic tube technique and plastic bottle technique have been conducted. The blast design parameters in all the blasts have been kept similar to conventional blast practice. Figure 2 presents section of blasthole for various techniques.

1. Conventional blast practice

Five trial blasts have conducted by adopting the usual practice of the mine at the sites. The blast holes have been drilled in a staggered pattern. Later, the holes have been charged with SME up to a two-thirds height of the blast hole. Rest of the blast hole is stemmed using drill cuttings. 17 ms hole-to-hole delay, 42 ms row-to-row delay, and 250 ms down-the-hole delay have been used in all the blasts. The hole diameter is 115 mm. The hole depth, spacing and burden vary between 9.0-9.5 m, 4.5-5.0 m and 3.5-4.0 m respectively. Three cartridge boosters have been used in each column. Each of the cartridge boosters has a weight of 0.50 kg, density of 1250 kg/m^3 and rated VOD of 4800 m/s. The shock tube system has been used for initiation with in-line firing pattern.

2. DAG blasting technique

This is a recently developed technique of explosive consumption reduction (Balakrishnan et al., 2019a, 2019b, 2019c). In DAG blasting hollow balls made from recycled plastic have been used to induce air-gaps in the explosive column to save about 20% explosive by volume. Due to their smaller size, the air-gaps are well distributed throughout the SME column, maintaining the continuity in the column.

3. Air-deck technique

In this method, air-decks have been inserted in between the explosive column. The air-decks are created using wooden spacers of 1.2 m length to replace about 20% of explosive by volume. The air-decks have been inserted manually in the explosive column after charging explosive up to a height of about 2.8 m.

⏩ 4. Plastic tube technique

In this method, plastic tubes have been used to introduce air-gaps in the explosive column. Four to five plastic tubes have been inserted manually at fixed time intervals during charging of blast hole to replace about 20% of explosive by volume. These tubes are of 83 mm diameter and 540 mm in length.

⏩ 5. Plastic bottle technique

In this method, hollow plastic bottles have been used to induce air-gaps in the explosive column. The maximum diameter and length of the bottle are about 76 mm and 270 mm respectively. Twelve to fifteen bottles have been inserted manually at fixed time intervals during charging of hole to replace about 20% explosive by volume.

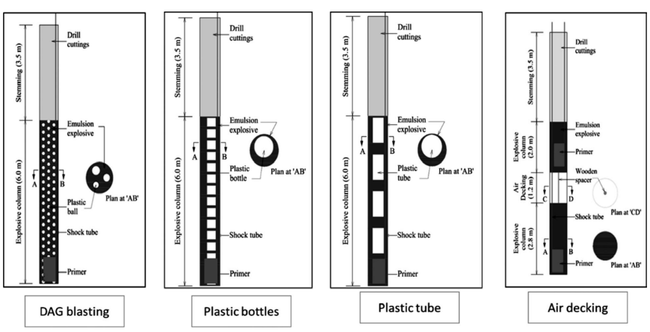

Figure 1 : Sections of the blastholes for different techniques

⏩ Measurement of ground vibration and air overpressure

PPV and air overpressure have been measured in all the trial blasts using two seismographs (Minimates plus and Minimate) manufactured by Instantel Inc. Canada. Figure 2 shows the seismographs properly placed for recording particle velocities and air overpressure. For all trial blasts, the Minimate Plus and Minimate are placed at distances 100-120 m and 180-200 m respectively from the blasting face.

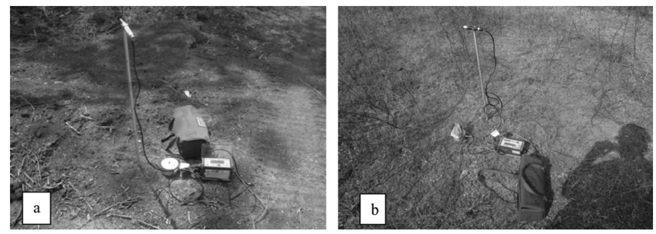

Figure 2 : Snapshots of measurement of PPV and air overpressure using (a) Minimate plus; (b) Minimate

⏩ Results

⏩ 1. Conventional blast practice

The maximum charge per delay for conventional blasting technique varies from 70-76 kg/ delay. The peak particle velocity for all the trial blasts measured at 100-120 m and 180-200 m from the blasting face varies from 18.70 mm/s to 26.07 mm/s and 11.81 mm/s to 14.41 mm/s respectively. The corresponding air overpressures varies from 137.7 dB(L) to 146.9 dB(L) and 118.6 dB(L) to 136.0 dB(L) respectively. Table 1 presents the distance of seismograph from the blasting face, the maximum charge per delay, peak particle velocity and sound level for conventional blasting technique.

Table 1 : Ground vibration and air overpressure levels for conventional blasting technique

Trial blast	Distance from blasting face (m)	Maximum charge per delay (kg)	Peak particle velocity (mm/s)	Sound level (dB)
First	100-120	75	21.46	146.9L
	180-200	75	12.51	136.0L
Second	100-120	75	19.28	140.8L
	180-200	75	12.76	133.1L

Trial blast	Distance from blasting face (m)	Maximum charge per delay (kg)	Peak particle velocity (mm/s)	Sound level (dB)
Third	100-120	70	18.70	137.7L
	180-200	70	11.81	126.0L
Fourth	100-120	72	23.74	143.9L
	180-200	72	14.41	118.6L
Fifth	100-120	76	26.07	144.1L
	180-200	76	14.27	122.8L

2. DAG blasting

The maximum charge per delay for DAG blasting technique varies between 55-62 kg/ delay. The peak particle velocity for all the trial blasts measured at 100-120 m and 180-200 m from the blasting face varies from 11.34 mm/s to 16.90 mm/s and 5.49 mm/s to 8.68 mm/s respectively. The air overpressure for all the trial blasts at 100-120 m and 180-200 m from the blasting face vary from 120.4 dB(L) to 127.9 dB(L) and 100.0 dB(L) to 114.6 dB(L) respectively. Table 2 presents the distance of seismograph from the blasting face, the maximum charge per delay, peak particle velocity and sound level for DAG blasting technique.

Table 2 : Ground vibration and air overpressure levels for DAG blasting technique

Trial blast	Distance from blasting face (m)	Maximum charge per delay (kg)	Peak particle velocity (mm/s)	Sound level (dB)
First	100-120	60	16.90	127.9L
	180-200	60	5.98	107.5L
Second	100-120	60	12.47	122.4L
	180-200	60	7.90	108.0L
Third	100-120	55	14.32	124.5L
	180-200	55	7.39	114.6L
Fourth	100-120	58	11.34	125.8L
	180-200	58	8.68	108.1L
Fifth	100-120	62	11.58	120.4L
	180-200	62	5.49	100.0L

3. Air-deck technique

The maximum charge per delay for air-deck technique varies between 55-62 kg/ delay. The peak particle velocity for all the trial blasts measured at 100-120 m and 180-200 m from the blasting face varies from 12.84 mm/s to 15.75 mm/s and 5.41 mm/s to 8.90 mm/s respectively. The corresponding values of air overpressure vary from 118.8 dB(L) to 133.5 dB(L) and 109.2 dB(L) to 128.8 dB(L) respectively. Table 5.3 presents the distance of seismograph from the face, maximum charge per delay, peak particle velocity and sound level for air-deck technique.

Table 3 : Ground vibration and air overpressure levels for air-deck technique

Trial blast	Distance from blasting face (m)	Maximum charge per delay (kg)	Peak particle velocity (mm/s)	Sound level (dB)
First	100-120	62	15.75	131.3L
	180-200	62	8.90	128.8L
Second	100-120	60	13.83	128.4L
	180-200	60	8.64	117.9L
Third	100-120	55	13.76	133.5L
	180-200	55	5.41	100.0L
Fourth	100-120	55	13.84	130.6L
	180-200	55	7.46	109.2L
Fifth	100-120	60	12.84	118.9L
	180-200	60	6.45	113.7L

⏩ 4. Plastic tube technique

The maximum charge per delay for plastic tube technique varies between 52-60 kg/ delay. The peak particle velocity for all the trial blasts measured at 100-120 m and 180-200 m blasting face varies from 10.08 mm/s to 14.02 mm/s and 5.02 mm/s to 8.97 mm/s respectively. The air overpressure for all the trial blasts at 100-120 m and 180-200 m distance varies from 113.8 dB(L) to 129.8 dB(L) and 100.0 dB(L) to 122.4 dB(L) respectively. Table 4 presents the distance of seismograph from the blasting face, maximum charge per delay, peak particle velocity and sound level for plastic tube technique.

Table 4 : Ground vibration and air overpressure levels for plastic tube technique

Trial blast	Distance from blasting face (m)	Maximum charge per delay (kg)	Peak particle velocity (mm/s)	Sound level (dB)
First	100-120	52	10.08	123.2L
	180-200	52	5.02	105.0L
Second	100-120	60	14.02	129.8L
	180-200	60	4.83	112.4L
Third	100-120	55	13.74	113.8L
	180-200	55	7.10	122.4L

Trial blast	Distance from blasting face (m)	Maximum charge per delay (kg)	Peak particle velocity (mm/s)	Sound level (dB)
Fourth	100-120	58	11.24	121.7L
	180-200	58	7.89	100.0L
Fifth	100-120	60	10.16	122.0L
	180-200	60	8.97	114.9L

5. Plastic bottle technique

The maximum charge per delay for plastic bottle technique varies from 55-62 kg/ delay. The peak particle velocity for all the trial blasts measured at 100-120 m and 180-200 m from the blasting face varies from 9.65 mm/s to 14.62 mm/s and 6.27 mm/s to 7.36 mm/s respectively. The corresponding air overpressure levels vary from 124.5 dB(L) to 134.3 dB(L) and 100.0 dB(L) to 112.0 dB(L) respectively. Table 5 presents the distance of seismograph from the blasting face, maximum charge per delay, peak particle velocity and sound level for plastic bottle technique.

Table 5 : Ground vibration and air overpressure levels for plastic bottle technique

Trial blast	Distance from blasting face (m)	Maximum charge per delay (kg)	Peak particle velocity (mm/s)	Sound level (dB)
First	100-120	60	12.51	124.5L
	180-200	60	7.36	112.0L
Second	100-120	62	13.47	125.0L
	180-200	62	6.27	108.4L
Third	100-120	57	12.76	133.5L
	180-200	57	7.01	100.0L
Fourth	100-120	58	14.62	127.7L
	180-200	58	6.58	109.5L
Fifth	100-120	55	9.65	134.3L
	180-200	55	6.73	110.2L

Discussion

All the techniques for explosive consumption reduction have significantly reduced ground vibration and air overpressure levels than conventional blasting technique. The PPV for conventional blasting measured at 100-120 m and 180-200 m distance varies from 19.28 mm/s to 26.07 mm/s and 11.81 mm/s to 14.41 mm/s respectively. The corresponding values for DAG blasting varies from 11.34 mm/s to 16.90

mm/s and 5.49 mm/s to 8.68 mm/s respectively. The PPV for trial blasts of air-decking measured at 100-120 m and 180-200 m distance varies from 12.84 mm/s to 15.75 mm/s and 5.41 mm/s to 8.90 mm/s respectively. The peak particle velocity for trial blasts of plastic tube technique measured at 100-120 m and 180-200 m distance ranges from 10.08 mm/s to 14.02 mm/s and 5.02 mm/s to 8.97 mm/s respectively. The peak particle velocity for trial blasts of plastic bottle technique measured at 100-120 m and 180-200 m distance varies between 9.65 mm/s to 14.62 mm/s and 6.27 mm/s to 7.36 mm/s respectively.

The air overpressure for conventional blasting at 100-120 m and 180-200 m distance ranges from 137.7 dB(L) to 146.9 dB(L) and 118.6 dB(L) to 136.0 dB(L) respectively. The corresponding values for DAG blasting ranges from 120.4 dB(L) to 127.9 dB(L) and 100.0 dB(L) to 114.6 dB(L) respectively. The air overpressure for all the trial blasts of air-decking measured at 100-120 m and 180-200 m distance varies from 118.8 dB(L) to 133.5 dB(L) and 109.2 dB(L) to 128.8 dB(L) respectively. The air overpressure for all the trial blasts of plastic tube technique at 100-120 m and 180-200 m distance ranges from 113.8 dB(L) to 129.8 dB(L) and 100.0 dB(L) to 122.4 dB(L) respectively. The air overpressure for all the trial blasts of plastic bottle technique at 100-120 m and 180-200 m distance varies between 124.5 dB(L) to 134.3 dB(L) and 100.0 dB(L) to 112.0 dB(L) respectively. The air overpressure for all the trial blasts at 100-120 m and 180-200 m distance varies from 118.8 dB(L) to 133.5 dB(L) and 109.2 dB(L) to 128.8 dB(L) respectively. The air overpressure for all the trial blasts at 100-120 m and 180-200 m distance ranges from 113.8 dB(L) to 129.8 dB(L) and 100.0 dB(L) to 122.4 dB(L) respectively. The air overpressure for all the trial blasts at 100-120 m and 180-200 m distance varies between 124.5 dB(L) to 134.3 dB(L) and 100.0 dB(L) to 112.0 dB(L) respectively.

Introduction of air-gaps in the column replaces the explosive, leads to a reduction in the value of maximum charge per delay. The maximum charge per delay is the most dominant parameter that affects the PPV and air overpressure given that the geotechnical and climatic conditions are similar provided the distance of seismograph from the face has also been kept similar. This is authenticated from the fall in PPV values at 100-120 m and 180-200 m distance respectively for various explosive consumption reduction techniques. The air overpressure has also decreased at 100-120 m and 180-200m distance respectively for various explosive consumption reduction techniques. The ground vibration and air overpressure depend on many other known and unknown factors. It is therefore not pertinent to discuss the reasons for minor variation in the PPV and air overpressure levels among different techniques. Future researches can be conducted for such studying such variations.

Conclusion

The blast-induced ground vibration and air overpressure can cause damage to the structures surrounding the mining locality. In recent times the ground vibration and air overpressure are drawing more and more attention due to increased human settlements near the mine. In this research, trial blasts have been conducted using four different explosive consumption reduction techniques namely, DAG blasting, air-deck technique, plastic tube technique and plastic bottle technique. The techniques for a reduction in explosive consumption have been found effective in reducing PPV and air overpressure levels when compared to conventional blast practice. These techniques are found feasible in the regions which have restrictions on the charge per delay due to excessive blast-induced ground vibration and air overpressure.

Acknowledgement

The authors want to acknowledge the managements of M/s Century Cement for providing the necessary facilities for conducting the experiments. The authors also want to acknowledge the director of the National Institute of Technology (Raipur, India) for providing the necessary support to carry out the field trials.

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