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उत्तरी जोन गाजियाबाद / Northern Zone, Ghaziabad

Satish D. Chiddarwar

Dy. Director General of Mines Safety

Northern Zone, Ghaziabad

Message

I am happy to know that AKS University, Satna is celebrating the National Mining Day on 01.11.2023 at Satna in collaboration with the Indian Mining & Engineering Journal and the inaugural session will be followed by technical session where students will be given opportunity to present their papers.

The National Mining Day celebration provides a platform for statutory organization, academic institutions and industry to discuss issues related with present and future mining, new technologies and R & D prospects. Such programme gives opportunities to the students to strengthen their knowledge and also for deciding their field of carrier. The Indian Mining & Engineering Journal is already playing important role in this regard.

It is also learnt that the awards will be presented to the students for their outstanding achievement which will encourage them to achieve next level of competency.

I wish the celebration a grand success.

S.D. Chiddarwar

(Satish D. Chiddarwar)

PUKHRAJ NENIVAL
BE (Mining), MBA (HR), FCC (Coal), FCC (Metal-R), PGDPMIR (Delhi), PGDEL (NLSIU-Bangalore), Quantum Computing Certificate (Microsoft & MeitY)

**Regional Controller of Mines,
Indian Bureau of Mines - Jabalpur
& Chairman-MEAI, Jabalpur Chapter**

MESSAGE

The Indian Mining industry is undergoing several technological, legislative as well as socio-economic changes for ensuring sustainable and safe operations. To ensure skill in the Mining Industry, job aspirants, future mining engineers, educational institutions and professional bodies have to shoulder greater responsibilities.

In this context, the oldest professional body of Mining Sector i.e. Mining Engineers' Association of India has declared 1st November as the National Mining Day. This annual celebration aims to foster a sense of togetherness among all those associated with mining.

It is this context, Mining Engineers' Association of India [MEAI] had laid much emphasis on the future mining engineers who are studying at various institutions for their diploma and degree programs in mining. MEAI had taken up with the Chapters to open up Students Chapters throughout the country. As a part of this initiative, Under the Jabalpur Chapter- a Student Chapter was formally inaugurated at AKS University, Satna Campus on 17th August 2023 bringing together 500 and more student members to its fold.

The National Mining Day celebration represents a significant milestone in the activities of the Student Chapter.

I extend my best wishes for the success of the program.

[Pukhraj Nenival]

Bhola Singh
Chairman cum Managing Director
भोला सिंह
अध्यक्ष सहप्रबन्ध निदेशक

नार्दर्न कोलफील्ड्स लिमिटेड
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MESSAGE

It is a matter of great pleasure to know that the ***Indian Mining & Engineering Journal (IMEJ)*** *is going to celebrate* ***"Indian Mining Day-2023"*** *on 1st November, 2023 at AKS University Satna.*

Mining is an integral part of India's industrial landscape, contributing significantly to our nation's growth and development. In this era of rapid change, the focus on mining safety and sustainability is paramount. We must prioritize the well-being of our workforce and the conservation of environment.

I commend the students and faculty members who will be presenting papers on mining safety and sustainability at this event. The focus of IMEJ on these crucial aspects of mining is commendable and will undoubtedly help in shaping the future of our industry.

I extend my best wishes to the organizing team, the students, and all the participants for a successful celebration of Indian Mining Day. May the discussions and idea-sharing at this event pave the way for a safer, more sustainable, and prosperous mining sector.

B Singh.

(Bhola Singh)

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Ahmedabad Chapter

S. N. Mathur
President-Elec MEAI

Message

It gives me immense pleasure to bless the young Mining Engineers when they have formed a Student Chapter at AKS University, Satna. I was told that AKS University has excellent teaching laboratory and field trip facilities for students of Diploma and Degree in Mining. Our Jabalpur Chapter is the mentor for this new chapter. I thank Jabalpur Chapter Chairman and members for starting a student chapter at AKS University.

I wish all the best for the new chapter which will be inaugurated by our Chairman Jabalpur Chapter on 17th August 2023.

(S.N Mathur)

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Use of Red Mud in Mining Voids

Aditya Jha* Dr G.K.Pradhan**

ABSTRACT

The mining industry generates significant quantities of waste materials, resulting in environmental and operational challenges. One such waste material, red mud, is a byproduct of the alumina extraction process and is commonly disposed of in large storage facilities, posing a potential risk to the environment. To address these challenges and explore sustainable alternatives, this study investigates the feasibility of using red mud as a backfill material for mining voids. The objective of this paper is to assess the engineering properties and environmental impacts of utilizing Red Mud as a backfill material. The study includes laboratory experiments to determine the geotechnical characteristics of red mud, such as strength, permeability, and compaction properties. Additionally, various physical and chemical tests are conducted to evaluate the environmental suitability of red mud as a backfill material, considering leaching potential and long-term stability. The results indicate that red mud possesses desirable geotechnical properties, including adequate strength and compaction characteristics, making it a potential candidate for backfilling in mining voids. Furthermore, the chemical analyses demonstrate a low potential for leaching harmful substances, which mitigates concerns related to groundwater contamination and environmental risks.

The utilization of red mud as a backfill material offers several advantages, including waste management benefits, cost-effectiveness, and sustainability. By repurposing this industrial waste, mining companies can reduce the need for traditional backfill materials and alleviate the demand for natural resources, contributing to a more circular economy and reducing the industry's environmental footprint.

INTRODUCTION

RED MUD

Red mud, also known as bauxite residue, is a byproduct of the Bayer process, which is used to extract aluminum from bauxite ore. Bauxite is the primary source of aluminum, and the Bayer process involves refining bauxite to extract alumina (aluminum oxide). During this process, the insoluble components of bauxite, including iron oxides, silica, and other impurities, become concentrated in the red mud.

Red mud gets its name from its characteristic red color, which is due to the presence of iron oxides. The composition of red mud can vary depending on the source of bauxite and the specific refining process used. It typically consists of fine particles with a high pH level, making it highly alkaline.

The management of red mud has been a significant environmental concern due to its caustic nature and potential for environmental impacts if not properly managed. Improper disposal of red mud has been associated with environmental pollution, particularly if it contaminates water bodies or soil. In some cases, red mud spills or leaks from storage facilities have caused extensive damage to ecosystems and human communities.

Efforts have been made to find sustainable solutions for red mud management, including recycling and reusing it in various applications such as construction materials, soil amendments, and in the production of iron or cement. Additionally, research continues to find innovative ways to reduce its environmental impact and find economically viable uses for this byproduct.

HOW RED MUD IS PRODUCED ?

Red mud is a bye product of the Bayer process, the principal means of refining bauxite to produce Alumina. The resulting alumina is the raw material for producing aluminum by the Hall-Heroult process. A typical bauxite plant produces one to two times as much as red mud as alumina The ratio is dependent on the type of bauxite used in the refining process and the extraction conditions.

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Mining of bauxite in India is purely by opencast methods and they occur mostly in hill tops at very high altitudes. Alumina is extracted using sodium hydroxide under conditions of high temperature and pressure. The insoluble part of the bauxite (the residue) is removed, giving rise to a solution of sodium aluminate, which is then seeded with an alumininum hydroxide crystal and allowed to cool which causes the remaining aluminium hydroxide to precipitate from the solution. Some of the aluminium hydroxide is used to seed the new batch, while the remainder is calcined (heated) at over 1000oC in rotary kilns or fluid flash calciners to produce aluminium oxide(alumina) .The alumina Content of the bauxite used is normally between 42% and 50% but ores with a wide range of alumina content can be used. The aluminium compound may be present as Gibbsite (Al(OH)3),Boehmite (´-AlO(OH)) or Diasphore (á-AlO(OH)).The residue invariably has a high concentration of iron oxide which gives the product a characteristic of iron oxide which gives the product a characteristic red color.

SOURCES OF RED MUD

The major sources of red mud include:

Bauxite mines: Bauxite ore is mined from open-pit mines or underground mines in various countries with significant bauxite deposits. The main bauxite-producing regions include Australia, China, Brazil, India, Guinea, and Indonesia.

Alumina refineries: Bauxite when treated by Bayer process the impurities in bauxite, such as iron oxides, silica, and titanium dioxide, become concentrated in the form of red mud during the refining process.

It's important to note that the composition of red mud can vary depending on the specific bauxite source, refining process, and other factors. Additionally, the generation of red mud is a concern due to its caustic nature and potential environmental impact if not managed properly. Efforts have been made to find sustainable solutions for red mud management, including recycling and reusing it in various applications to reduce its environmental impact.

BAUXITE & ITS TYPES

The elemental form of aluminium is not found in nature since it is a reactive metal. A vast variety of minerals, typically in combination with other oxides, most notably silica and iron oxides, contain aluminium almost completely as the oxide.

Gibbsite (Al(OH)3), also known as Alumina trihydrate or hydrate (Al2O3.3H2O) in the business, Boehmite (AlO(OH)), and Diaspore (which has the same chemical composition as Boehmite), are the aluminium minerals found there. One of the primary sources of aluminium is bauxite, a mineral of aluminium. It usually contains Kaolinite, Goethite, Hematite, and trace amounts of Anatase (TiO2) and Ilmenite (FeTiO3 or FeO.TiO2) along with other minerals like Boehmite("-AlO(OH)), Gibbsite (Al(OH)3), and Diaspore (á-AlO(OH)) (Liu et al., 2011). These bauxite ores have very different crystal formations from one another.

Production of Aluminum from Bauxite: This industry is divided into 2 segments. The plants for obtaining alumina from bauxite ore, such plants are located near bauxite mines and plants for reduction of Alumina into Aluminum, such plants are located near the cheap source of electricity. For producing 1 ton of aluminum, 6 tons of bauxite is required (which produces 2 tons of alumina).In this process, aluminium ore is treated with concentrated sodium hydroxide. Soluble sodium aluminate is formed which is filtered off. The filtrate on heating with water gives aluminium hydroxide which gives alumina on strong heating.

Indian bauxite can be categorized into four different groups based on the mineralogy and order of preference:

- Gibbsitic bauxite (Eastern ghats, Gujarat and coastal deposits of western India)
- Mixed Gibbsitic- Boehmitic bauxite (Boehmite < 10%, Diaspore < 2%; parts of Western Ghats and Gujarat deposits
- Boehmitic bauxites (Boehmite > 10 and Diaspore < 2%; Central Indian bauxite
- Diasporic bauxites (Diaspore > 5%; J&K and some part of Central Indian and Gujarat deposits.

In this paper Red Mud generated from east coast bauxite occurring at Baphlimali Mines located in the Raygada-Nuapada districts of Odisha, of Utkal Alumina International has been discussed. The mined bauxite is refined at the Alumina plant down hill.

Specification of Bauxite to produce Alumina :

To produce alumina (aluminum oxide) from bauxite ore through the Bayer process, certain specifications or

Figure 1 : Shows Bauxite Deposits of India

characteristics of the bauxite are required. The quality of the bauxite plays a crucial role in determining the efficiency and economics of the alumina production process. The key specifications of bauxite for alumina production include:

Chemical Composition: The bauxite must have a high content of aluminum oxide ($Al2O3$), typically ranging from 30% to 60% or more. Lower-quality bauxite with lower alumina content might require more extensive processing and result in higher production costs. Additionally, low levels of impurities like iron oxides ($Fe2O3$), silica ($SiO2$), and titanium dioxide ($TiO2$) are desirable to minimize the generation of red mud and increase the overall yield of alumina.

Reactive Silica: Reactive silica refers to the silica content that can easily dissolve during the Bayer process. High levels of reactive silica in bauxite can lead to silica scaling in the process, which reduces the efficiency and productivity of alumina production. Low reactive silica content is desirable to avoid these issues.

Particle Size: Bauxite should have a relatively fine particle size to ensure efficient digestion during the Bayer process. Smaller particle sizes increase the surface area for the chemical reactions to occur, leading to better alumina extraction.

Available Alumina: The available alumina content refers to the portion of alumina in bauxite that can be easily extracted using the Bayer process. Higher available alumina content is preferred to maximize the alumina yield and reduce the amount of unreactive alumina in the red mud.

Moisture Content: Low moisture content in bauxite is desirable to reduce energy consumption during the drying process before digestion.

Beneficiation: Bauxite beneficiation involves removing impurities and improving the quality of the ore before processing. This can include techniques such as washing, screening, and magnetic separation to enhance the alumina content and reduce impurities.

These specifications may vary depending on the specific alumina production process, the technology used, and the requirements of the alumina refinery. However, in general, bauxite with high alumina content, low impurities, and favorable particle size distribution is preferred for efficient and cost-effective alumina production.

Production of alumina from Bauxite: Alumina (aluminum oxide) is produced from bauxite ore through a refining process known as the Bayer process. The Bayer process involves several steps to extract alumina from bauxite:

Crushing and Grinding: The mined bauxite ore is first crushed into smaller particles and then ground into a fine powder to increase its surface area for the subsequent extraction process.

Digestion: The ground bauxite is mixed with a hot, concentrated solution of sodium hydroxide (NaOH) in high-pressure digesters. This step dissolves the alumina content of the bauxite into the sodium hydroxide solution while leaving behind impurities such as iron oxides, silica, and titanium dioxide. The chemical reaction is as follows:

$$Al2O3(s) + 2\ NaOH(aq) + 3\ H2O(l) \rightarrow 2\ NaAl(OH)4(aq)$$

Clarification and Precipitation: The sodium aluminate solution obtained from the digestion step is then cooled and allowed to settle to remove the remaining solid impurities. During this stage, any undissolved impurities settle as a red mud, and the clear sodium aluminate solution is separated.

Seed Addition: To initiate precipitation, “seed crystals” of aluminum hydroxide are added to the clear sodium aluminate solution. These seed crystals act as nuclei around which aluminum hydroxide molecules can form.

Precipitation: The addition of seed crystals triggers the precipitation of aluminum hydroxide from the sodium aluminate solution. The reaction can be represented as follows:

$$2\ NaAl(OH)4(aq) \rightarrow Al(OH)3(s) + Na2O(aq) + 2\ H2O(l)$$

Separation and Washing: The precipitated aluminum hydroxide, which is now in the form of fine particles, is separated from the sodium aluminate solution using various separation techniques like filtration. The separated solids are then washed to remove any remaining sodium hydroxide.

Calcination: The washed aluminum hydroxide precipitates are then heated at high temperatures (around 1000-1100°C) in rotary kilns or fluidized bed calciners to remove the chemically-bound water and convert the aluminum hydroxide into alumina.

$$2\ Al(OH)3(s) \rightarrow Al2O3(s) + 3\ H2O(g)$$

Final Product: The resulting product of this calcination step is alumina (aluminum oxide) in the form of a fine white powder. This alumina is the primary raw material used in the smelting of aluminum metal through electrolysis.

CHEMICAL & PHYSICAL COMPOSITION OF RED MUD

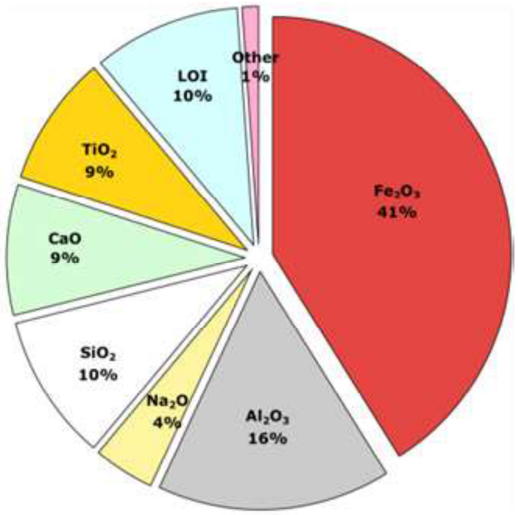

Figure 2: Chemical composition of red mud

General Properties of Red mud presented in table 1

Table 1

Property	Range
Specific Gravity	2.6-3.1
pH Value	11.0-12.5
Pulp Density(g/cm^3)	1.1-1.3
Initial % of solids in Slurry	8.0-36.0
Settling Rate	1.0-3.0
% Solids after 24 hours	25-36
Particle size	<10mm 60-90 <1mm 10-20

Typical Chemical Composition of Red Mud presented in Table 2

Table 2

Major element	Conc.(wt%)	Minor element	Conc.(mg/kg)	Minor element	Conc.(mg/kg)
Fe	4.53-50.10	U	50-60	Mn	86
Al	4.42-16.06	Ga	60-80	Y	60-150
Si	2.16-14.86	V	730	Ni	31
Na	0.98-7.79	Zr	1230	Zn	20
Ca	0.39-16.72	Sc	60-120	Lartharides	0.1-1
Ti	0.98-5.34	Cr	497	-Th	20-30

Both free and bound forms of sodium can be found in red mud. Free sodium is the caustic soda that gets incorporated throughout the digesting process and stays with the red mud despite repeated washings. It is present in the entrained liquid of red mud slurry. The forms of free sodium include NaOH, Na_2CO_3, $NaAlO_2$, and others. These alkaline particles in red mud are responsible for the red mud's pH . The desilication phase used in the Bayer process to remove kaolinitic silica from bauxite is what causes the bound soda in the red mud. Bound soda exists as the sodalite complex, which can be written as $3(Na_2OAl_2O_32SiO_2)Na_2X$ (X=CO22-, 2OH-, SO42-,2Cl-)7. About 20–25% of the sodium in red muds is free, with the remaining portion being sodalite complex. Regarding particle size distribution, red mud is a very fine substance. Red mud typically has particles that are smaller than 10 microns in size. Depending on how finely the bauxite is ground, the specific surface area (BET) of red mud ranges from 10 to 30 m^{2}g-1.

DISPOSAL OF RED MUD NEAR ALUMINA PLANT

The disposal of red mud, also known as bauxite residue, near an alumina plant is a critical aspect of alumina production that requires careful consideration and management to minimize environmental impacts. Red mud is a highly alkaline and caustic material that can pose environmental risks if not handled properly. There are several common methods of red mud disposal near alumina plants:

Impoundments or Tailings Ponds: One common method of red mud disposal involves creating large impoundments or tailings ponds near the alumina plant. Red mud slurry is pumped into these ponds, where it settles, and the supernatant water is decanted. The settled red mud eventually dries, forming a solid waste deposit. Proper engineering and design of the ponds are crucial to prevent leakage and ensure stability.

Figure.3.Source: CPCB

Dry Mud Stacking: Dry stacking is another method where red mud is mechanically stacked in layers to form a dry, solid deposit. This approach reduces the need for large ponds and can provide better environmental control. However, it requires more land area and appropriate compaction to ensure stability.

Figure 4: Mud Dewatering & Compaction

Figure 5: Dry Mud Stacking

Filter Press: Drum filters and plate and frame filter presses are used for filtration to recover caustic soda, which results in a more controllable bauxite residue by lowering the moisture level.

A typical press filter used for Red Mud is shown in Figure 6.

Figure.6

Landfilling: Red mud can be placed in engineered landfills designed to prevent environmental contamination and control leachate. Landfilling is considered a safer method for long-term storage if the landfill is well-designed and properly managed.

Backfilling: In some cases, red mud may be used as a backfill material for mined-out areas or for reclamation and rehabilitation of disturbed lands near the alumina plant. Current practices of management & disposal in Indian industries are presented in Table 3.

PROBLEMS ASSOCIATED WITH DISPOSAL OF RED MUD

Red mud disposal is associated with several significant environmental and safety challenges, which have been a concern for the aluminum industry and communities living near alumina refineries. Some of the problems associated with red mud disposal are as follows:

- **High alkalinity:** Red mud is highly alkaline due to the presence of sodium hydroxide in the Bayer process. When improperly managed, it can lead to soil and water alkalization, causing damage to ecosystems and aquatic life.

Table 3: Types of disposals in different industries in India

Sl.No.	Name of the Industry	Management and disposal practices
1.	M/s Hindalco Industries Ltd,Muri Jharkhand	Dry stacking of Red Mud stared in June, 2002. Filter Press is used to increase solid content up to 75%. The filer cake i.e. the Red Mud from the filter press is collected into trucks through hoppers and hauled to the Red Mud disposal ponds. There are 4 Red Mud disposal ponds, of which 03 are exhausted.
2.	M/s Hindalco Industries Ltd ,Renukoot, Uttar Pradesh	Both Drum Filters and Filter press (which caters to only 25% of total Red Mud generation) are used by the unit. There are 11 Red Mud disposal Ponds.
3.	M/s Utkal Alumina International Ltd., Odisha	There are 04 ponds, of which 3 are operational. The pond A was originally designed for wet storage and now being used for dry mud stacking since June, 2017. Filter Press is used and dry stacking of Red Mud is being followed.
4.	M/s Vedanta Limited, Lanjigarh, Odisha	High concentration slurry disposal of red was followed till 2013. After 2013, High Pressure Membrane Filtration Technology is being used for dry stacking of Red Mud. The filter-cake Red Mud is transferred to the pond via truck, spread in lifts to dry with a dozer and compacted with a sheep roller.
5.	M/s NALCO Ltd., Damanjodi, Odisha	Thickened Tailing Disposal (TTD) System are used wherein the Red Mud is discharged into a pond (RMP) at solid consistency varying between 54% - 60% at one point for having a sloped deposit. Installation of Filter Press is under Process.
6.	M/s BALCO Ltd., Korba, Chhattisgarh	The unit is non-operational since September, 2009. There are 07 Red Mud disposal ponds. One of the ponds has been reclaimed and plantation has been done. The remaining have been converted to ash dykes.
7.	M/s Hindalco Industries Ltd, Belgaum, Karnataka	Filter Press are used to reduce moisture content. Part of this Red Mud is sent to Cement industries for utilization and remaining is stored in Red Mud Ponds. There are 02 Red Mud disposal ponds available with the unit designed for wet ponding and the same got started used for the dry mud stacking.
8.	M/s MALCO Ltd., Tamil Nadu	The unit is non-operational since November, 2008. However, during its operational days, moisture of Red Mud was reduced using drum filters and hauled through trucks and stacked in the Red Mud Pond.

- **Land use and habitat destruction:** The large volumes of red mud generated by alumina refineries require vast land areas for disposal. This can result in habitat destruction and loss of valuable agricultural or forested land.

- **Risk of dam failures:** Red mud is often stored in large containment dams called tailings dams. The failure of these dams can lead to catastrophic environmental disasters, as seen in the Ajka alumina plant accident in Hungary in 2010, where a red mud dam failure resulted in the release of toxic slurry, causing significant environmental and human impacts.

- **Water contamination:** Improper containment or accidental spills of red mud can lead to water contamination. Red mud contains various heavy metals and other contaminants that can leach into the surrounding environment, polluting water bodies and affecting groundwater quality.

- **Airborne dust and pollution:** Red mud can generate airborne dust during transportation and disposal, which may contain hazardous materials. Prolonged exposure to this dust can be harmful to human health and can affect nearby communities and workers.

- **Long-term storage and management:** Red mud is a long-term waste product, and its disposal requires proper management and monitoring for decades or even centuries. This poses challenges in ensuring the continued stability and safety of containment structures.

- **Regulatory compliance:** Meeting regulatory standards for red mud disposal can be complex and costly. Compliance with environmental regulations and permits is crucial to avoid fines and penalties
- **Public health concerns:** The potential for red mud to contaminate water sources and release harmful substances poses risks to the health of nearby communities and ecosystems.

- **Costs of disposal:** Proper disposal and management of red mud require significant financial resources. Finding economically viable and sustainable disposal solutions is a continual challenge for alumina refineries.

Efforts are ongoing to find alternative uses for red mud and develop innovative technologies to minimize its environmental impact. Recycling, reusing, and finding beneficial applications for red mud are essential steps in reducing the volume of waste generated and mitigating the problems associated with its disposal.

USES OF RED MUD

Utilization of Red mud: Efforts have been made to find beneficial uses for red mud, such as in the production of building materials, cement, and soil amendments. By finding valuable applications for red mud, the amount requiring disposal can be reduced.

RED MUD POND

Site selection to store Red Mud is influenced by - geology, hydrology, and proximity to water bodies. Regular monitoring of the disposal site, groundwater quality, and surface water is crucial to detect and address any potential environmental impacts. Proper engineering and containment measures must be implemented to prevent leakage, erosion, and other hazards. After the disposal facility's useful life, proper reclamation and rehabilitation should take place to restore the site's natural conditions. It's important to note that the specific disposal method and management practices may vary based on local regulations, environmental considerations, and the technological capabilities of the alumina plant. Responsible management of red mud disposal is essential to minimize its environmental impact and ensure sustainable alumina production.

Mine site rehabilitation: Red mud can be used for land reclamation and mine site rehabilitation. Its use in re-vegetation programs can help restore the disturbed areas, stabilize slopes, and prevent erosion, thus promoting ecological recovery.

Dust suppression: The fine particle size and binding properties of red mud make it effective in controlling dust emissions from mine haul roads, stockpiles, and other areas prone to dust generation.

Acid mine drainage treatment: Red mud contains alkaline compounds, which can neutralize the acidity associated with acid mine drainage (AMD). When placed in or near areas affected by AMD, red mud can help mitigate its environmental impact.

Tailings management: Red mud can be used as a component in tailings dams to improve their stability and reduce seepage. Its addition can help bind the tailings particles, making the dam more secure and less prone to failures.

Backfilling in mine operations: Red mud can be mixed with other materials to create a suitable backfill material for underground mining operations. This approach provides a more environmentally friendly alternative to traditional backfill materials.

Water treatment: The adsorption properties of red mud can be harnessed for water treatment purposes, particularly in removing heavy metals and other contaminants from mine wastewater.

Erosion control: Red mud can be applied as a surface cover or mulch in erosion-prone areas to prevent soil loss and enhance soil stability.

Road construction and maintenance: Utilizing red mud in road construction and maintenance near mines can improve road durability, reduce maintenance costs, and provide a sustainable use for the waste material.

Metal recovery: Red mud contains residual metals, such as iron and titanium, which can be potentially recovered and recycled, reducing the overall waste generated by the mining and refining processes.

Sustainable practices: Incorporating red mud into mine operations aligns with the principles of sustainable mining and waste management. By repurposing this byproduct, mines can reduce their environmental footprint and promote circular economy practices.

MINING VOIDS

A mining void refers to an area or space left behind after the extraction of minerals, ores, or other valuable materials through mining activities. When mining operations remove natural resources from the earth, they create voids or cavities in the ground, which can vary in size and shape depending on the mining method and the type of material extracted. Mining voids can occur both underground and on the surface.

There are two main types of mining voids

Underground mining voids: These voids are typically created when minerals or ores are extracted from beneath the earth's surface. Underground mining methods, such as longwall mining, room and pillar mining, and block caving, can leave extensive voids and tunnels underground.

Surface mining voids: Surface mining involves removing minerals or ores from large open pits or quarries. As the material is extracted, significant holes or depressions are formed on the surface, leaving behind surface mining voids.

Figure 7: Source: AWA

Mining voids can present various challenges and risks, including:

Subsidence: The removal of material from underground can cause the ground above to collapse or subside, leading to surface deformations and potential damage to buildings and infrastructure.

Water accumulation: Mining voids may fill with water, forming lakes or ponds. If not managed properly, these water bodies can become sources of contamination and pose safety risks.

Environmental impacts: Mining voids can disrupt natural habitats and ecosystems, affecting flora and fauna in the area. They can also alter groundwater flow patterns, leading to changes in water quality and availability.

Safety hazards: Unstable ground in and around mining voids can pose risks to human safety, especially in areas where voids are close to residential or industrial areas.

Limitations on land use: Mining voids can restrict or limit future land use options, making it challenging to develop or utilize the land for other purposes after mining operations have ceased.

Statutory provisions governing use of Red Mud - Backfilling of Mining Voids as per MMDR Act & MCDR

The Mineral Conservation and Development Rules (MCDR), 2017, are part of the Mines and Minerals (Development and Regulation) Act (MMDR Act), 1957, which governs the regulation of mining activities in India. The MCDR provides guidelines and regulations for various aspects of mining, including backfilling of mining voids. Backfilling is the practice of filling the voids created by mining activities with suitable materials to restore the land and ensure stability. Here are some key points regarding backfilling of mining voids as per the MMDR Act and MCDR:

1. **Backfilling as a requirement**: The MCDR mandates that mine operators must backfill the voids created during mining operations to the extent possible. The idea is to restore the land to a safe and stable condition after the extraction of minerals.
2. **Backfill materials**: The rules specify that the backfill materials should be non-toxic, non-hazardous, and not detrimental to the environment. These materials can include waste rock from mining operations, fly ash, mill tailings, and other suitable materials approved by the regulatory authorities.
3. **Environmental clearance**: The backfilling plan and the choice of materials must be included in the Mine Closure Plan, which is submitted for environmental clearance before the start of mining activities.
4. **Backfilling during the operation**: In underground mining operations, progressive backfilling is encouraged to maintain the stability of the mine voids as mining progresses. This practice helps to minimize the risk of subsidence and ensures the safety of miners and surrounding areas.
5. **Surface mining**: In surface mining operations, backfilling may be required to reclaim and restore the land after mining is completed. Backfilling can help to shape the land, reduce erosion, and facilitate re-vegetation.
6. **Monitoring and compliance**: Mine operators are required to monitor the backfilled areas and ensure that the backfill materials remain stable and do not pose any environmental hazards.
7. **Financial assurance**: Mine operators are required to provide financial assurances, such as environmental bonds or funds, to cover the costs of mine closure and land reclamation, including backfilling activities.
8. **Community engagement**: The MCDR emphasizes the importance of involving local communities in mine closure and backfilling plans to ensure their concerns and traditional rights are considered.

It is essential for mining companies to adhere to the guidelines provided by the MMDR Act and MCDR to ensure responsible mining practices and minimize the environmental impacts of mining activities. Proper backfilling of mining voids is a crucial aspect of mine closure and land reclamation, and it plays a significant role in restoring the affected areas to a safe and sustainable condition.
Top of Form

The Ministry of Environment, Forest, and Climate Change (MoEFCC) in India has issued guidelines and notifications related to the use and management of red mud, also known as bauxite residue. below are some of the key guidelines issued by MoEFCC in the context of red mud:

1. **Guidelines for Safe Disposal of Red Mud:** The MoEFCC has issued guidelines to ensure the safe disposal of red mud to prevent environmental pollution and harm to human health. These guidelines may include recommendations for storage, containment, and monitoring of red mud disposal sites.
2. **Guidelines for Utilization of Red Mud in Construction:** MoEFCC has provided guidelines for the beneficial use of red mud in construction projects, such as in road construction, embankments, and building materials. These guidelines aim to promote sustainable practices and reduce the environmental impact of waste disposal.
3. **Environmental Clearance:** Mining and alumina refining projects that generate red mud are required to obtain environmental clearance from the MoEFCC. The clearance process includes an assessment of the environmental impact of the project and measures to mitigate potential adverse effects, including those related to red mud management.
4. **Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016:** Red mud is considered an industrial waste, and its management is governed by the Hazardous and Other Wastes Rules. The MoEFCC provides guidelines for the proper

handling, storage, and transportation of red mud under these rules.

CASE STUDY

In order to study the use of red mud Baphlimali Bauxite Mine of M/S Utkal Alumina International was selected. This mine is the captive mine of the Alumina Plant located at a distance of about 30 km from the mine. R-O-M bauxite is crushed by the crushing plant is transported to the alumina plant by a conveyor system of 18 km Long.

LOCATION

The mine is located in Paikkupakhai, Karanjkupakhal, Dhuturapass, Danadabad & Chandragiri village of Rayagada district and Durumusi, Suryagada & Kendumundi of Kalahandi district in Odisha state.
The mine falls in the Survey of India Topo sheet No. 65 I/15 between latitude
19°19’22.78234" to 19°22’11.40057" N and longitude 82°56’17.25017" to 82°59’06.92518" E.

Figure 8: Area Map of Baphlimali Mining Lease

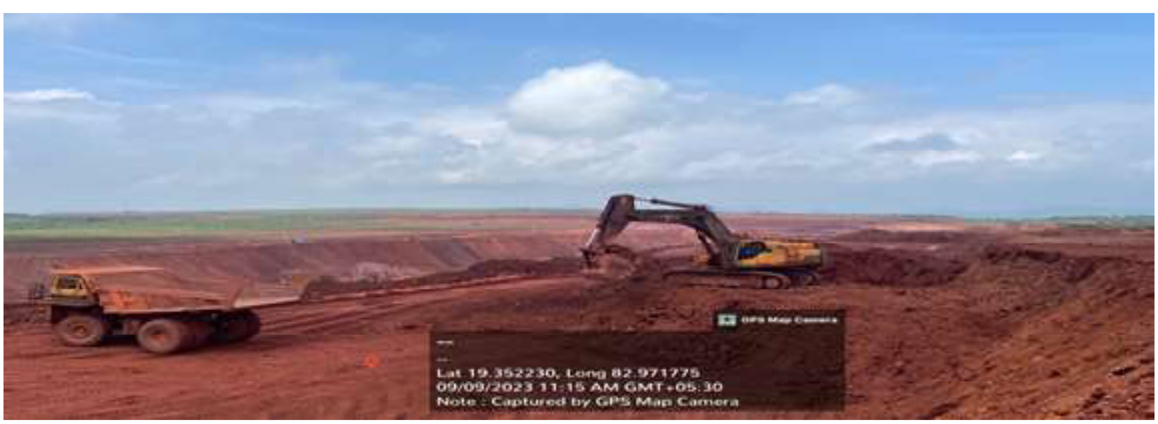

Figure 9: Mine working

SALIENT FEATURES OF THE MINE

Utkal Alumina International Limited (UAIL), is a 100 per cent subsidiary of Hindalco Industries Limited, a metals flagship of Aditya Birla Group.

A leading alumina refinery, Utkal operates in the Rayagada district of Odisha. It comprises a 2.12MTPA alumina refinery, captive Baphlimali bauxite mines of 8MTPA with valid lease title up to February 2048, and a captive co-generation power plant of 90MW along with a 5MW solar power plant.

Utkal was originally conceptualized in 1992-93 to set up an alumina refinery with captive bauxite mines by four reputed corporate groups – Alcan, INDAL, Tata and Norsk Hydro Aluminium of Norway.

INDAL was merged with Hindalco in the year 2004 and subsequently UAIL became a 100 per cent subsidiary of Hindalco in FY 2008.

Utkal is a world-class refinery with state-of-the-art technology from the world's acclaimed technology supplier, Rio-Tinto-Alcan. Utkal has the best quality bauxite as its input, and an environment-friendly logistics network for bauxite, other raw materials and product alumina through conveyors and railway networks. The bauxite for UAIL is sourced from Baphlimali mines and travels over an 18km Long Distance Conveyor (LDC), which is one-of-a-kind in the world. UAIL enjoys the global leadership position in terms of product quality, energy consumption and cost per ton.

Utkal caters to 70 per cent of Hindalco's smelter's alumina requirement and supplies to other domestic and international market. The high purity alumina supplied by Utkal enables our new age smelters to produce niche aluminium metal catering to sectors like aviation and space, defense, food & beverage, transport etc. Initially Utkal's greenfield plant was commissioned with a capacity of 1.5MTPA in 2013-14. This plant was expanded to 2.12MTPA and commissioned in August 2021.

Year after year, Utkal is surpassing its own record in terms of production, efficiencies, customer expectations, societal stewardship and creating a new benchmark. As a responsible corporate citizen, Utkal is committed to socio-economic well-being and transforming the lives in the tribal hinterland. Utkal is relentlessly working to improve the Human Development Index of our community through various CSR, CR & sustainability initiatives in 232 villages of 25 gram panchayats of Odisha. Utkal is touching the lives of more than 201,000 people through its five pillars of interventions - education, healthcare, sustainable livelihood, rural infrastructure and addressing the issues of their socio-economic concern. Utkal's unique multi-stakeholder-based initiatives are in line with the Sustainable Developmental Goal of United Nations 2030. -(Photo of the mine with Geotag)

Geology of the mine: The plateau top is generally flat and the elevation in the M.L area varies from 990m to 1094m. The highest point on the plateau is at 1094 meter above mean sea level.

Baphlimali bauxite deposit in the M.L area belongs to east-coast bauxite where the lateralization was developed at the expense of Gneisses and Schists. The dominant rock assemblage in the region comprises Khondalites and its variants. These are high grade metasediments of Argillaceous, Arenaceous and Calcareous nature. The Bauxite deposit is a weathering product of Precambrian Khondalite group, a high-grade meta-sediment Gneiss, comprising chiefly of Quartz, Garnet, Feldspar-Sillimanite with or without Graphite. This M.L area is a part of Baphlimali hill which is characterized by a NE-SW trending Bauxite capping surrounded by Khondalite on the slopes. Bauxite forms an integral part of the lateritic profile which is derived by the in-situ chemical weathering of the khondalite. It occurs as a gently rolling or near flat blanket capping the steeply dipping khondalites. The boundary of the bauxite capping is marked at scarp faces. In general, the foliation of khondalite strikes due NNE – SSW and dips at 400 to 800 towards ESE direction. Khondalite is the parent rock of bauxite which occurs at the base of bauxite profile. It is heterogeneous in mineral composition and essentially Quartz-Orthoclase, Garnet Sillimanite Gneiss. Most of it is rich in Feldspar, Sillimanite and Garnet. Partially Lateritised Khondalite (PLK) / Partially Kaolinised Khondalite (PKK) lies below the Bauxite.

TRANSPORTATION

Once red mud is generated, it needs to be transported from the refining facility to storage or disposal sites following MoEFCC norms. In Utkal alumina International method used for transporting red mud is by trucks and pipe line . Red mud is loaded onto trucks for distance of about 11 km from the plant to storage facility.

Production capacity is presented in table 4

Table 4

	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
ROM Bauxite (Mill Tonnes)	4528000	4729000	4790000	4927000	5297000	5299830	5998340
Alumina Produced (Mill Tonnes)	1402100	1499600	1499700	1553600	1667495	1559209	1747916
Quantity of Red Mud generated	1914000	1974000	2049000	2082000	2232705	2055236	2408045

Figure 10: Truck Yard near Red mud Pond

STORAGE

Red mud is the residue generated during manufacture of alumina having the leachable caustic content in disposed liquor <10 gpl expressed as NA_2CO_3 in slurry condition with 40-60% water and solids .The water is being removed by pressure filter and in semi-dry condition (78% of solids) disposed in impervious pond known as Red mud Pond. The entire red mud pond is divided into 4 parts ,Pond A B C & D. Out of these pond A & B are meant for Mud Storage .Pond C is meant for collection of Supernatant Liquor (SNL) from the pressure filter and mud storage pond A & B . Pond D is meant for freshwater emergency storage. The 1/3rd of the pond A mud storage dam is lined with Clay along with 1.5mm thick single layer HDPE liner. Pond D is also lined with Clay along with 1.5mm thick single layer HDPE liner & is currently having fresh water in it.

The Mud storage dam also has a leachate drain under the HDPE liners and connected to the lowest point out side the dyke in a collection pipe and the leachate water is being pumped back to the pond C for storage, Fixed rain gun water sprinkling system has been provided at the red mud pond to prevent dust from red mud pond area. In addition to this ,water tankers are being deployed for water sprinkling on roads of the red mud pond.

Currently in Utkal Alumina International Ltd. Utilization of red mud is carried out for backfilling of mining voids & for cement industries In Figure 10 below shows the backfilling of red mud in mining voids which is covered by tarpaulin sheets to protect it form rain water to avoid contamination of soil and ground water.

Figure 11: Stacked Red mud

Figure 12: Red Mud Pond

Figure 13: Red Mud Ponds

Figure 14: Red Mud dewatering Pond

CHEMICAL COMPOSITION OF RED MUD OF UTKAL ALUMINA INTERNATIONAL LIMITED

Red mud is alkaline in nature and is having pH of about 11 to 12.5.The typical chemical composition of the Red mud is given in table below:

LOI%	TA%	THA%	T-SIO_2	Fe_2O_3	TiO_2	Na_2O	P_2O_5	V_2O_5	CaO
6.93	13.54	4.33	6.35	61.31	3.94	2.87	0.22	0.11	1.84

At AKS University the Red Mud samples were tested for their chemical composition as well as pH.The investigation carried out by Chaurey (2018) and his team, had investigated the relationship between soil micro flora and soil pH. From the soil samples microbial load was determined by serial dilution method. pH of culture media within 7- 11 for the isolation of bacteria.

STORAGE OF RED MUD AT THE SITE OF DISPOSAL

Red mud is stored in ponds which are lined by thick walls on the periphery for avoidance of overflow and ponds are also lined with liners for separating it from the ground soil to avoid contamination of soil and underground water. Red mud is highly alkaline, which can result in increased pH levels when used in mining voids. Adequate care is taken to test the samples in respect of their chemical composition and remesdial actions to make them safe for disposal.

CONCLUSION

Red Mud disposal, storage, transport etc cause sever impact on the land area as well as the general environment. The efforts made by regulators, research institutions, R&D establishment of Aluminium companies is quite encouraging. While Utkal Alumina is using red mud for cement making, other units in India need to increase efforts in this direction.

Figure 15: Red mud Storage facility

Figure 16: Backfilled mine void by Red mud

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Annexure 1

Reproduced below the opinion of several researchers and industry experts on the use of Bauxite Residue (IIT-Bombay, 2018).

A. BAUXITE RESIDUES

Dr. Gautam Goswami, TIFAC
"Mission required for utilization of Red Mud in a sustainable way i.e., extraction of
Rare earths, Titanium and other important components".
Dr. P. K. Banerjee, Hindalco Industries Ltd.
"At National level a comprehensive strategy needs to be made on utilization of Red Mud mainly in following four areas a) Cement making b) Bulk construction – road, embankment, marine clay reclamation and mine backfilling c) man-made soil for green belt development d) metal / non-metal value recovery. On each of these areas a National level Mission Projects need to be launched and these projects to be executed in parallel. Participating organizations in these missions will be from industry, academia, research labs and Govt. agencies and preferably, to be led by industry sector. The projects should focus on complete solution including commercial scale technology development, demonstration & implementation, preparation of policy guidelines and standards. Initiative on Bulk construction application is already being led by IIT Bombay along with Hindalco Industries Ltd. The same may be extended to other partnering organizations including Govt Agencies to make it the Mission Project and expedite demonstration and implementation of the technology.

NITI Aayog initiative to extract Rare Earth Element (REE) from Red Mud (and Fly Ash) to be expanded to complete Value Recovery (Fe, Ti, Al, REE & Non-metals). The committee recommendation on the potential process/technology route, expected by Dec, 2018, to be taken as the basis for launching the National Mission Project for technology demonstration on Value Recovery from Red Mud". Mr. Anjan Das, Confederation of Indian Industry "Confederation of Indian Industry spearheaded by its National Committee on Environment, which has members from varied sectors of Indian Industry, works extensively on key policy issues in the areas of Plastic Waste Management, E-waste management, and Environment and Forests Clearances. In addition, the committee has a specific focus on key challenges associated with environmental compliance, and hazardous waste management is one of them. With an objective to facilitate increased utilization of hazardous waste in the country, especially in the cement kiln, CII has been advocating streamlining of waste coprocessing trials, through extensive interaction with regulatory authorities. Hazardous waste can be utilized in cement kilns, leading to lesser GHG emissions. However, on account of a few challenges, we are losing a

large opportunity to reduce GHG emissions and conservation of coal. These challenges are: business is getting impacted because industries are not able to comply to the green supply chain principles; some of the SPCBs are advising industries to approach CPCB for obtaining approval for co-processing; a large amount of hazardous and non-hazardous wastes is getting disposed in an unsustainable manner causing environmental hazard; at locations, where landfill and incineration option are not feasible, the industries are facing huge waste disposal issues such as in Tirupur, Goa, etc. CII made a presentation on the requirement of modifying the CPCB guidelines, based on the data analysis from the results of Proceedings of Brainstorming Session: IBPs for Sustainable Development
IIT Bombay | 22nd August, 2018
co-processing trials that are already approved by CPCB. All these trials had demonstrated that the baseline emissions of the kiln were not impacted considerably due to co-processing of wastes. Although the CPCB guidelines were amended, however, varied interpretations at SPCB
level need to be addressed and removed.

CII's Green Business Centre (GBC) at Hyderabad, has been working in the industrial waste since many years. CII's GreenCo Rating Program promotes Waste Management in industrial facilities by inventorizing all waste generated and establishing specific waste generation; encouraging industries to Commit & Reduce specific waste generation year-onyear; encouraging adoption of waste management practices in line with waste treatment hierarchy; facilitating 'Waste Exchange' through unique online platform www.ciiwasteexchange.org; substitute & reduce waste generation by promoting tools like Lifecycle Analysis (LCA), Environment Product Declaration (EPD). CII promotes Coprocessing of Alternate Fuels & Raw materials (AFR) in cement plants by creating a platform to bring all stakeholders like cement plants, generators, policy makers (PCBs & ULBs) and technology suppliers; creating awareness, capacity building and enabling conducive policy framework; support implementation, scaling-up success stories, develop implementation models and forecast generation and utilization; technical feasibility, developing business models, waste fuel mapping, etc. are also carried out to help industries pursue AFR utilization further. CII-GBC also works on phytoremediation with applications in the agricultural waste. industrial waste, sanitary and urban waste, landfills and lake & river rehabilitations".

Mr. Ulhas Parlikar, ACC Ltd. "Cement kilns can manage reasonable quantum of red mud in plants when petcoke is utilized as fuel. We would be happy to utilize it in workable proportions". Mr. Vinod Sood, IBAAS

"Several Government agencies and Institutions are carrying out research work on bulk utilization of Red Mud and Ash on behalf of Aluminium industries. Since a lot of progress has been made by IIT, it is not necessary for producers to initiate and progress individually on this. It would be advisable to make a single central agency and all producers be asked by NITI Aayog or similar such agency to direct their activities through IIT. This will not only save funds but it will also allow the producers to present a united front to the agencies involved in granting clearance.

The need of the hour is to find a fast solution for safe disposal of Red Mud by backfilling in Mines. The Central/State Government agencies are to be educated accordingly. While recovery of precious metals is definitely an excellent idea but the generation of waste from such processing needs to be studied in greater detail. So far only RUSAL has come to a pilot scale plant for recovery of Scandium". Mr. Tapan Mappat, Vedanta Alumina Ltd. "Regarding the possibilities of the red mud utilization, it is suggested that the respective stakeholders work together on projects pooling in expertise, funds, experience etc. to bring a sustainable solution to the society as a whole. To reduce the freight expenses related to the railway transport of the red mud by relooking into the freight classification.

Proceedings of Brainstorming Session: IBPs for Sustainable Development
IIT Bombay | 22nd August, 2018
To look in to option of making a mission red mud similar in the lines of Fly Ash mission. Suggested that all the 3 stakeholders of red mud to work in coordination while representing the case to the Central government bringing the technical studies to the table. Suggested that Central Government help in setting up a model plant for utilization of the red mud which could be replicated at different locations. The academia has to bring the research papers on table to identify the right solution to the problem".
Dr. P S R Babu, Alcon Pvt. Ltd.
"Study utilization economics at resource-limited condition (now regional and in future the whole world) before by-product disposal. Example- recovery of iron from red mud is not viable in India but it is processed in other part of the world.

Design processes towards atomic level recovery- in aluminum manufacturing, more than 5% alumina is wasted through red mud. Today, technologies are available for safe utilization and disposal of all industrial/social IBPs, the willingness for implementation is the only need of this hours". Mr. K. Venkatesh, Hindalco Industries Ltd. "Govt. Policy, Protocol by MoEF&CC/CPCB should be made so as to obtain necessary approval from Statutory bodies easily". Mr. Ganaraj K., IIT Bombay "Application of alkaline IBPs for treatment of Acid Mine Drainage, mine backfilling, embankment construction etc.".

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Use of Alternate Fuel in ANFO Explosives

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ABSTRACT

Ammonium Nitrate & Fuel Oil mix as a column explosive is widely used due to its several benefits as well as safety aspects. Till the enactment of Ammonium Nitrate Rules of 2012, Ammonium Nitrate transport, storage used to be very simple. After these Rules, the system adopted was same as those for industrial explosives. Also use of ANFO as a column charge used to be in confirmity with provisions of Indian Ex0plosive Rules 2008 and CMR 207 & MMR 1961. A very safe explosive uses Diesel Oil/HSD as fuel added with AN in a ratio of 94(AN):6(HSD) by weight percentage. In last few years due to hike in cost of HSD, several scientific studies were undertaken to use solid fuel as well as liquid fuel as Fuel of 6% addition. Use of waste lubricants as fuel in ANFO has been a very successful application area. The use has been based on scientific laboratory studies followed by field usage. Based on field usage, regulators were also associated to accept the use of waste lube oil as a fuel alongwith HSD. In many Indian Mines use of waste lube has helped in the problems associated with collection, transport, storage and disposal issues from environmental view point. HEMMs in mines use very large amount of lubricants for engines, gear box, brakes, hydraulic system etc. Since each lubricant has a specific and fixed life, they are replaced as per OEM norms. Also topping up of the lubes necessitated frequent oil level checks and refilling. These waste oil or lube oil generated from any mine are of very large quantities. Their removal or draining as well as handling and storage is a very hazardous and tedious job. Several government notifications are there to regulate the use, transport and storage of waste oil are in place. But for any mine they are posing lot of difficulties also. CPCB(2010) has stipulated norms for recycling for optimal use. In Indian mines, several attempts were made to select and use alternate fuel in ANFO by partially replacing HSD. In this context role of scientific organisations, regulators and mining companies alongwith the manufacturers of AN has been quite meaningful. There are CPCB(2010) stipulations/ norms for recycling for optimal use of waste lube oil.

INTRODUCTION

Ammonium Nitrate in prill form is used for blasting. Besides, AN is the best chemical to offer maximum Oxygen content to manufacture explosives (in cartridged as well as bulk SME form). Table 1, presents production of AN during last 3 years. To meet the huge requirement of AN for explosive grade, India also imports AN. Currently, M/s Deepak Fertilizers & Petrochemicals Corpn. Ltd. is the sole producer of prilled grade AN. During 2022-23, India imported AN for explosives of worth Rs. 15 1.98 Cores. For which PESO had issued 183 Nos. of licenses for Import of 469615 MT of Ammonium Nitrate. Majority of blasts in dry holes in non-coal opencast mines use ANFO. Very recently ANFO has been trial used in opencast coal mines of WCL, and MCL.

Table 1: Presents AN produced in India in last 3 years (Source : PESO Annual Report 2022-23)

Description	2018-19	2019-20	2020-21	2021-22	2022-23
Ammonium Nitrate(Solid)(MT)	452,939.15	380,889.40	358,321.13	390,664.450	395,486.901
Ammonium Nitrate(Melt)(MT)	359,075.44	351,852.90	369,572.40	468,076.112	515,212.569

Singh (2029) highlighted the suitability of ANFO vis-à-vis powder factor, size distribution in the muck pile, etc in Mines of Mahanadi Coalfields Ltd (MCL). In order to ensure effective use of explosive energy, use of ANFO is an encouraging step, and MCL can immensely benefit economically as well as from productivity view point. Every tonne of high explosive used in blasting releases 0.20 tonnes of CO2 into the atmosphere. By increasing use of ANFO and also alternate oxidizer and fuel in SME, CO2 release can be further reduced.

Singh et el (2021) further studied the operational and techno-economic view points about use of ANFO in MCL. They

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have studied the use of ANFO with low density porous prilled AN for dry hole blasting.

Summary of their cost benefit analysis –

(i) If we use 80% SME + 20% ANFO in place of 100 %SME at MCL:

a) Total consumption of SME in 2019-20: 40221594 Kg
b) Total Blasted OB Production in 2019-20: 86458760 M^3
c) Powder Factor achieved 2019-20: 2.15
d) Total Cost of SME (without GST)/kg: Rs 117.58 Crores.

ii) Cost for 80% use of SME

a. Total consumption of SME for 80% of Blasted OB production in 2019-20: 32177275 Kg
b. 80% of Total Blasted OB Production in 2019-20: 69167008 M^3
c. Powder Factor achieved: 2.15
d. Total Cost of SME (without GST)/kg: Rs 94.07 Crores

iii) Cost for 20% use of ANFO

a. Total consumption of ANFO for 20% of Blasted OB production in 2019-20: 5639990.7 Kg
b. 20% of Total Blasted OB Production in 2019-20: 17291752 M^3
c. Powder Factor (c x 42.63%+c): 3.07
d. Total Cost of ANFO @28.81 (without GST)/kg: Rs 16.25 Crores.

Total Cost Saving= [i-(ii+iii)]: Rs.7.27 Crores

AMMONIUM NITRATE FUEL OIL
Properties & Chemical Composition

ANFO is a mixture of AN prills and fuel oil (6% by weight of fuel oil) in which AN acts as the fuel. Diesel oil should have a flash point higher than 38an performance of ANFO depend upon the quality of the prill. Figure 1, shows different varieties/classes of AN prills.

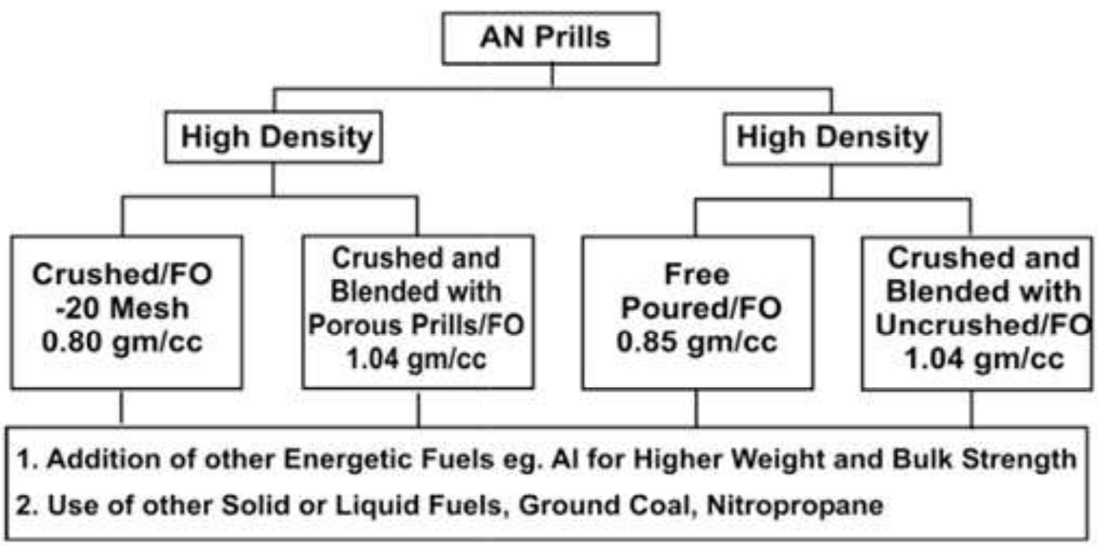

Figure 1: Classes of AN dry mixes

Prilled AN should contain low clay content, low moisture roughly between 6 - and 20-mesh U.S. standard screens (oil absorption, low particle density (073 to 0.82 g/cc), non -caking etc. ANFO is chemical reaction of AN/FO is:

Salient features

a) Low Cost
b) Safer to handle because of its lack of sensitivity
c) Best suitable for dry holes
d) Explosive is formed only after mixing. The best of oxygen balanced ANFO mixture is 5.7 fuel oil and 94.3 % AN prills.

$$3NH4NO3 + CH2 = 7$$

e) Percentage of fuel has a significant role in maintaining Oxygen Balance and quality of ANFO. Figure 3, shows the influence of fuel. Figure 4, Shows the Influence of Fuel Oil % on fume generation in CO in litres/kg at STP gases in litres/Kg at STP respectively. Fig.1.5, shows the influence of fuel oil on energy output.

Figure 2 & 3, Show the influence of fuel

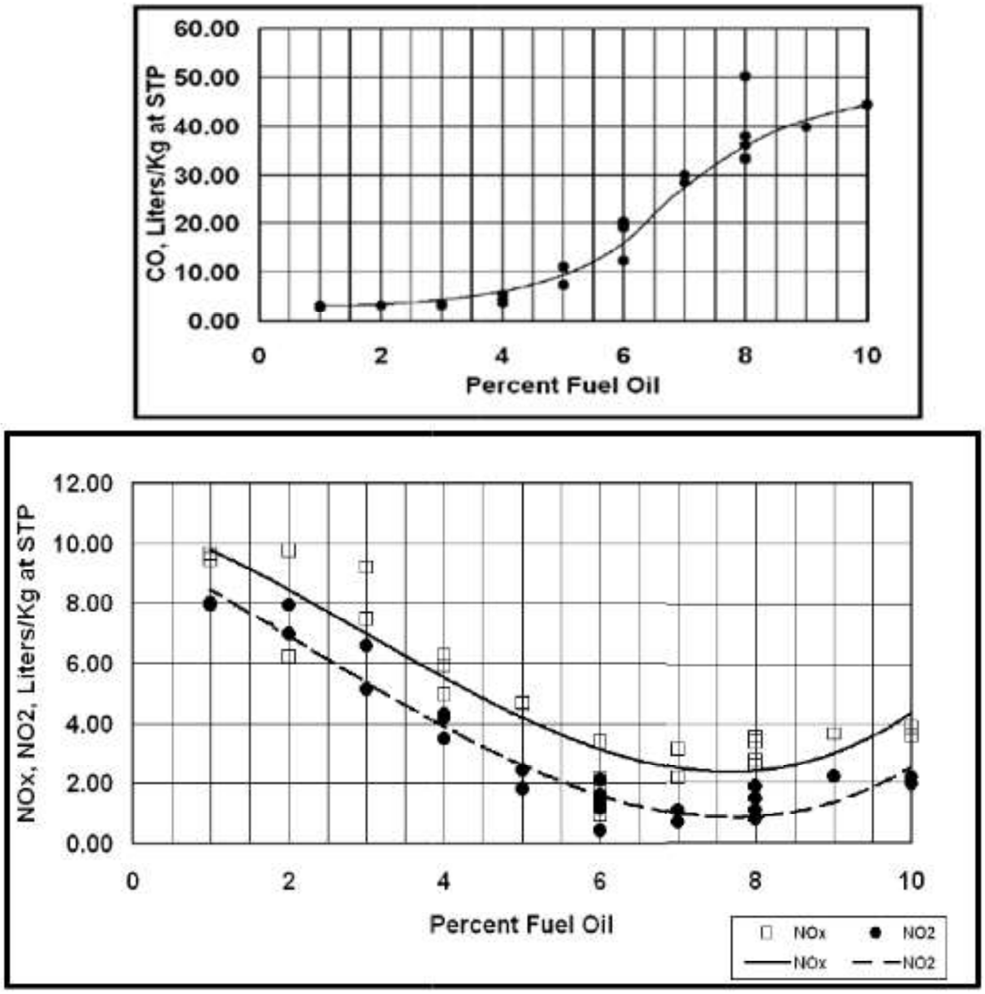

Figure 3 : Shows the Influence of fuel oil % on fume generation in other gases in litres/Kg at STP

f) Energy output expressed as Kcal/kg is also influenced by percentage of FO in the ANFO. Figure 4, shows the same.

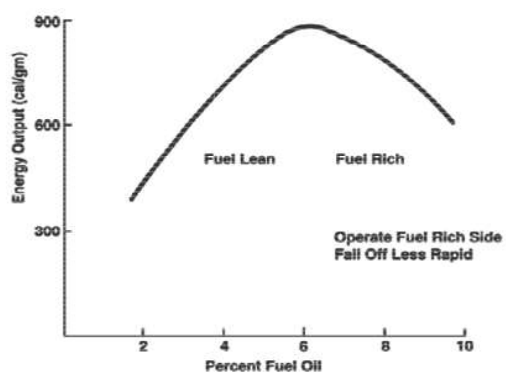

Figure 4: Shows the influence of FO percentage on Energy liberation from ANFO

USE OF SOLID FUELS

As early as 2010 and before in India, many mines have used saw dust, risk husk in varying percentages as solid fuel. Pal Roy et el (2012) reported about the effective blasting using mixture of ammonium nitrate, fuel oil, sawdust and used oil at limestone mine. Pradhan (2020) also in detail presented the use of solid fuel in ANFO.

USED/WASTE LUBRICANT OIL

Used oils are petroleum or synthetic oils that have been used and that, as a result of such use, are contaminated by physical or chemical impurities. Used oil is an identified hazardous waste in Australia and Internationally, and as such strict regulations govern its storage, transport, disposal and recycling. Used oil can be re-refined for use as an alternative to virgin oil, dewatered and filtered for use as an additive in other products, or burned as an industrial fuel . Alternatively, used oil can be disposed of by thermal destruction in purpose-built facilities that ensure appropriate handling and conditions to manage contaminated and limit health, safety and environmental risks. Mishandling or disposing of used oil the wrong way has the potential to pollute the environment and impact human health.

SOURCES OF WASTE OIL

1.Most mines through their Maintenance team, collect Oil samples at periodic interval. They conduct . Ferrography and Field Emission Scanning Electron Microscopy have been used for the wear particle analysis present in oil samples. Viscosity analysis and Fourier transform infrared spectroscopy have been done to investigate the degradation in quality and changes as compared to the initial structural properties of the lubricants.

2.The results obtained indicates wear in cylinder liner and piston ring. Copper, cast iron, alloy steel and ferrous oxide have been found as rubbing wear particles and cutting wear particles. Contamination level has also been found to be increasing in consecutive older oil samples. Chemical properties degraded with usage time and variations in oxidation and soot level have also been observed in every sample.

In India many mines do refine the used oil for topping up of the engine oil. The same system can be used to clean the waste oil meant for use in ANFO. Figure 5, shows the the cleaning system and blending of the same with HSD in one of the cement plants of North India. The AN manufacturer M/s Deepak Fertilisers have supplied the same wherever waste oil is being blended with ANFO.

Figure 5 : Waste Oil Blending system

To introduce this syem of replacement of HSD by waste oil, CIMFR had undertaken studies in Lab scale as well in the site of blasting. Ali Firoj, Prasad and others(2021) reported that , recycling waste lubricant oil is a valuable product has an immense commercial and environmental significance. The use of waste lubricant oil as a partial replacement of diesel oil of ammonium nitrate fuel oil (ANFO) explosives. Moreover, the effect on detonation properties and rock fragmentation patterns by the use of lubricant oil based ANFO in blasting operation has also been studied. The field trial experiments were carried out with lubricant oil based ANFO explosive to demonstrate the real applicability of the prepared explosive composition at Nimbeti Limestone open-pit mine of Shree Cement Limited, India. These explosive compositions revealed effective detonation performance. Importantly, air quality was analyzed during blasting operations to indicate that the emitted toxic fumes such as CO, NOx, and fine dust particles (PM2.5 & PM10) were found within the permissible limit at the mining area by the use of lubricant oil based explosives. Further, rock fragmentation analysis indicated that ANFO explosive compositions with 20%, 30%, and 40% (w/w) lubricant oil in diesel oil revealed good rock fragmentation as compared with normal ANFO in the conducted experimental blast.

WASTE OIL FUEL BLENDS FOR BULK EXPLOSIVES

Dyno Nobel have worked on a project to have reduction in bulk explosive fuel oil cost of up to 25% by suing waste oil blends in their Site Mixed Emulsion explosives. According to their laboratory and field studies, the direct replacement of up to 50% of the diesel in ANFO with waste oil delivers an immediate reduction in bulk explosives fuel oil costs to mining operations. Accordingly they have developed an advanced processing and blending technology called, CREATENERGY a purpose-built proprietary equipment and processes which enable the safe, reliable and consistent processing of waste oil to a standard required to replace up to 50% of the diesel in blasting. The equipment is containerised and modular to facilitate ease of transport, installation and customisation to specific site needs. Similar studies were made by other explosive manufacturers also.

OTHER LIQUID FUELS

ANVO

In countries where vegetable oil is available in abundance, in place of HSD Vegetable Oil was also used.

POLYOLEFIN WASTE-DERIVED PYROLYSIS OILS

Biessikirsk, A et el(2021) have worked on a research on the possible application of Polyolefin Waste-derived Pyrolysis Oils for ANFO Manufacturing.

BIODEGRADABLE/VEGETABLE OIL FUEL

Austn Powder had developed and is marketing Austinite HD consists of porous ammonium nitrate and mineral oil or biodegradable vegetable oil. Austinite HD has a little higher apparent density in comparison to Austinite S. Austinite HD is not water resistant and can only be used in dry conditions. Austinite it is not detonator sensitive.

Advantages
• High gas volume.
• Very low sensitivity against mechanical and thermal stress.
• Borehole volume is perfectly utilized, therefore high degree of efficiency.
• Perfectly free flowing.
• May be used for pneumatic loading.

Table-2, shows the properties of Austinite HD. Austin Powder had recommended the use of an Emulsion or a Cast Booster. The amount of booster explosive in boreholes with a diameter of 50 mm or more should be 6 % minimum of the total explosive mass. In boreholes with a smaller diameter the amount of booster explosive should be 10 % minimum. They have reported 6 months shelf life from the date of manufacture.

Table 2 : Shows the properties of Austinite HD when compared with standard ANFO

Properties	Austinite	ANFO(standard type)
Density (gm/m3)	0.80	0.820
Oxygen balance (%)	-1.6	+0.11
Gas volume (L/kg)	981	990
Heat of explosion(kJ/kg)	3752	4250
RWS (ANFO=100)	102	100
RBS(ANFO=0.85)	91	0.85
VOD (m/s)	2900	2000-2500

BIOWASTE DUNG AS ADDITIVE

Uranchimeg, E et el (2021), reported about the fuel in ANFO detonation parameters by biowaste addition. According to them, ammonium nitrate fuel oil (ANFO) composition modified by biowaste dung as additive to generate efficient explosion and to result low cost blasting. The experiment results of modified ANFO with biowaste dung as additive illustrate that physical stability and absorption increased by 5% percent compared to regular ANFO. Also was revealed that average detonation brisance increased from 20.5 to 27.5 mm and detonation speed increased from 2300 to 3800 m/s compared to regular ANFO. This modified ANFO is lowered blasting cost from 50 to 150 tugriks per 1kg ANFO compared to aluminium and TNT additives.

CIMFR had undertaken a research for feasibility and application of Bio-fuel as well as Low Cost and Diluted ANFO for Cost Effective and Safe Blasting Practices in Opencast Metalliferrous Mines in India as a part of its Project No. : GAP/MS/MOM/86/2010-11.Their research has been designed to cover

i) Development of an economical ANFO type explosive without jeopardizing safety and environmental concerns.
ii) To develop economical and environmental friendly blended ANFO explosive to achieve higher productivity with improved safety.
iii) Possible replacement of HSD with environment friendly bio-fuel/LDO in ANFO explosive. The alternative bio-fuels like Jatropha oil, Kusum oil, Mahua oil, Karanj oil, Saw dust and Rice husk were considered for the study. The fuel properties of bio-fuels such as density, viscosity, flash point, calorific value, pure point etc. were studied to establish their compatibility with AN prills.

ANFO with Bio-fuels were prepared in laboratory conditions. It is a booster sensitive explosive. The explosive properties like density and VOD under unconfined and confined conditions were studied with ANFO explosive. The detonation velocities tested and recorded were found to be satisfactory and efficient for rock blasting. The safety parameters with low cost ANFO were studied found safe to use for mining applications. They are easy to handle and produces less fumes. The trial blasts were conducted at Limestone and Manganese ore mines and provided satisfactory blast results.

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Physico-Mechanical Properties and Rock Mass Classification Systems of Manganese Ore Mine, UKWA

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ABSTRACT

The manganese orebody is 3-6 m thick and dipping at 30^0-45^0 towards NW with strike length at 5 km. The presence of phyllite intrusion in hangwall makes contact of orebody weak. It is proposed that development and mining of ore at 1650' L will be facilitated through the vertical shaft. The present report is comprised of application of empirical, analytical and numerical modelling approaches to design support system in galleries and stopes at Ukwa mine. 2.2 m long rock bolt fully resin grouted at the spacing of 1.0 m with applicable SSR as per DGMS guidelines and sand/waste rock as backfilling. In the case of the practical difficulty in providing long rock bolts in underground stoping operation, alternative support system could be considered as: to pre-reinforced the stope back and the hangwall with fully cemented long cable bolts at 2 m spacing and provide in-between 1.5 m long fully cemented grouted bolts. Thus effective spacing will be at 1 m with cable and rock bolts are installed in tandem. During the actual stoping operation, wooden chocks/steel cogs and steel props shall be provided as per SSR to prevent failure of the back/roof/hangwall. The shotcrete along with fully resin grouted rock bolts shall be considered for supporting all the entries to the stope. Also, if conditions demands then it should be used to reinforce the stope back to achieve stable and safe stoping environment.

Key world: RMR, RQD, Numerical Modelling, Manganese Ore.

INTRODUCTION

Ukwa mine is located in Paraswara (Baihar) Tahsil of Balaghat District, Madhya Pradesh. The village Ukwa is located on Balaghat–Baihar, all-time weather road, State Highway No. 26. It is 45 Kms from the district place Balaghat. The Balaghat-Baihar road almost touches South-Western part of the manganese deposit of Ukwa. The nearest rail head for the mine is Balaghat. It is important junction on Gondia and Katangi Rail line of South-Eastern Railway. The mine is situated in hilly terrain at an altitude of 2050'L (624.84 m) above MSL. The latitude is 21-58ÚNorth and Longitude is 80-28ÚEast.

In this mine, ore bed has been explored up to 1850, 1750 and 1650' levels along the entire strike length of 5.5 km. Ore body is continuous in nature and depth persistence is proved up to the 1950' level.

The MOIL management is planning to increase production of Ukwa mine and 2nd shaft is also being driven to facilitate ore recovery from the below levels. Also, development headings and drivages is being provided in footwall at 1650' L as compared to the earlier practice of driving in manganese ore itself. This is being done to introduce modified version of overhand cut-and-fill stoping method to increase production and productivity. The study will be limited to the present working area wherein a drift has been driven in footwall of the Ukwa mine of MOIL Ltd.

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GEOLOGY AND STRATA

The chief minerals of manganese ore are braunite, hausmanite, pyrolusite, bixbyite, hollandite, jacobsite, psilomelane etc. The ore horizon at Ukwa mine mainly consists of braunite mineral and small portions of pyrolusite and hausmanite. The manganese ore (braunite) is mainly formed due to the metamorphism of manganese bearing rocks (rocks containing spessartite, diopside, rhodonite etc).

The structurally Sausar belt is 215 km long and 35 km wide arcute synclinorium trending E-W. The major deformation is occurred at the central and south-west part of the Sausar belt which consists of succession of thrusts including the Deolaper Nappe, and major folds (recumbent). Ukwa is located at the margin of the Sausar group where the deformation is low. The minor folding of ore horizon with its host rock indicates low intensity folding. Structurally the deposit is not much disturbed as there is no major folding and faulting. A fault trending N64°W is observed at chainage 8000.

The formation of ore body and country rock belongs to Archean age group and is well exposed along the hill. The tabular ore body is outcropping on the hill top with general strike direction NE-SW (N58ÚE) with 6 km in length. The dip of the ore body varies from 30Úto 45Ú NW. The manganese ore belt (Lohangi Stage) comprises of braunite, psilomelene, pyrolusite and soft in nature The wall rock contact are phyllite and sericitic schist in hangwall and quartzite, quartzite schist in footwall side (Sita-Saongi Stage).

The topographically the mine is situated in hilly terrain at the altitude of 2050' L above MSL and 20Ú59' latitude and 80Ú20' longitude. The mine area is situated in forest which is mainly tropical and remains cool in the summer. The rainfall is about 80" and the rock being non water bearing the water level in summer is about 60' below the general ground level.

GEOTECHNICAL AND GEOLOGICAL OBSERVATIONS

The formation of ore body and country rock belongs to Archean age group and is well exposed along the hill. The tabular ore body is outcropping on the hill top with general strike direction NE-SW (N58ÚE) with 6 km in length. The dip of the ore body varies from 30Ú to 45Ú NW. The manganese ore belt (Lohangi stage) comprises of braunite, psilomelene, pyrolusite and soft in nature The wall rock contact are phyllite and sericitic schist in hanging wall and quartzite, quartzite schist in footwall side (Sita-Saongi stage). In hangwall side the ore is friable and inter-bands with clay and occasionally causes roof control problem. The thickness of ore body varies from 0.3 to 6.0 m. The ore body dip at Ukwa mine of the flat section is generally found varying from 20° to 30°. There are indications of foliation, parallel to bedding plane, due to deformation. Folding and mild intensity was also noticed along the strike of the deposit.

The phyllites are underlain by the manganese ore horizon, comprising alternating bands of manganese ore and magniferrous cherty-jespery quartzite, quartzite with extremely rare intercalations of schistose rocks. The ore horizon is exposed over a strike length of about 5 km. From the drilling data available, the ore thickness is found varying in-between 0.3 to 6.0 m with an average of 3.0 m. The inter-banding of the ore and quartzite is a characteristic feature of the Ukwa deposit. The close and regular nature of the bands simulates the banded hematite/ magnetite quartzite. The thickness of the ore and quartzite bands varies from 0.25cm to 0.5 m. The ore horizon consists of three units, based on the manganese contents viz. the bottom unit comprising quartzite with thin streaks of manganese ore, the middle unit comprising alternating bands of manganese ore and the Cherty-Jaspery quartzite and the top unit in composition similar to that of the bottom unit. The middle unit, which forms the main source of manganese ore termed as ore bed. The banding in the ore horizon representing bedding strike N 30^0 to 85^0 – S 30^0 to 65^0 and dips at 20^0 to 45^0 towards north-west and is parallel to the foliation of the schistose rocks.

The ore horizon is being more competent than the host rocks (immediate hangwall and footwall) has developed closely spaced orthogonal joints viz. dip (J1), strike (J2), and oblique (J3) joint sets, resulting in fragmentation/cubical formation of the ore material. The ore body breaks into thin rectangular slabs. It is because of closely spaced joints and the tendency of the ore horizon of easy splitting along the bedding of the ore, i.e. along J1. The ore body on hangwall side is associated with extremely soft and loose, fine grained clay and phyllitic rocks. The average thickness of roof layer varies from 1 to 10 cm and the mean orientations of the layers are mostly observed as parallel to each other. It is observed that footwall side ore body is more competent compare to that of the hangwall side. The joints are mostly tight and their spacing varies from 15 to 30 cm. The rocks of Sitasaongi and Munsar formation along with the ore horizon show three sets of joints which are as mentioned below:

Strike Joint: ENE-WSW / NW with steep northerly dip around 700 .

Dip Joint: NNW-SSE / NW-SE with sub vertical dips.

Oblique Joints: N-S with dips at 700 towards east and west.

PHYSICO-MECHANICAL PROPERTIES

The physico-mechanical properties of various rock types encountered in the developmental and stoping environment is presented in Table 1. The rock properties are considered from the various earlier studies conducted by CSIR-CIMFR for similar rock types at Balaghat and Ukwa mines. The average rock mass properties (Table 1) were determined with the application of RockLab software (RocScience Inc, Canada) and used in numerical modelling.

Table 1.: Geo-mechanical properties of rock tested (CIMFR Report, 2015)

Property	Ore body	H/W		F/W	
		Sericite Schist	Phyllite	Quartz Schist	Feldspathic Quartzite
UCS (MPa)	71	62	8.2	112	133±25
Young's Modulus (GPa)	13.1	10	0.06	12	58
Tensile Strength (MPa)	6	12.82	0.82	18	12±9
Poisson's ratio	0.14	0.37	0.25	0.4	0.3
Unit Weight (ton/m^3)	2.8	2.8	2.5	2.7	2.8
Cohesion (MPa)	-	4	-	-	-
Friction Angle (^{o})	-	62	-	-	-

Table 2.: Average rock mass and fill properties used in numerical modelling studies

Parameter	Orebody	Footwall	Hangwall	Phyllite	Fill Material
Young's Modulus, E (GPa)	10	10	10	0.6	0.2
Poisson's Ratio	0.25	0.25	0.25	0.25	0.15
Cohesion, c (MPa)	2.6	2.6	1.27	0.3	-
Angle of Internal friction (Degrees)	33	33	27.5	22	-
Density (Kg/m^3)	2700	2700	2700	2500	1500

IN-SITU STRESS

The measured in-situ stress values are not available for any underground manganese mine, since, a theoretical equation for estimating the mean horizontal stress for Ukwa mine is derived. The in-situ horizontal stresses were estimated from the rock elasticity modulus considering at 10 GPa. The horizontal in-situ stresses so obtained for Ukwa mine are as given in below equation (CMRI Report, 2002).

$$S_H = 3.2 + 0.0122\ H \qquad (1)$$

$$S_V = 0.027H \qquad (2)$$

Where, SH is the average horizontal stress (MPa), ã is average rock density in MPa/m (generally considered at 0.027 MPa/m super-incumbent strata pressure for Indian conditions) and H is the depth cover in m. Using the above equations in-situ stress is determined in the case of various levels (Table 3).

Table 3.: In-situ stresses determined

Level	Depth (m)	S_V (MPa)	S_H (MPa)
1650 Level	117	3.2	4.6
1750 Level	87	2.4	4.3

BIENIAWSKI'S ROCK MASS RATING (RMR) SYSTEM

The rock mass rating (RMR) system was initially developed at the South African Council of Scientific and Industrial Research (CSIR) by Bieniawski (1973, 1989). The Geo-mechanics classification system is based on the parameters: Strength of intact rock material, Drill core quality (RQD), Condition of joints, Spacing of joints, Ground water condition, and Fracture orientation rating. The average RQD for the ore-body and HW/FW rock is considered at 55. The rock mass rating in the case of Ukwa mine is presented in Table 4. The determined adjusted RMR after fracture orientation correction is at 35, while basic RMR is at 50. The RMR at 35 corresponds to rock class IV representing poor rock type. From the chart estimation of safe span reveals that for a rock with a RMR equal to 35 – a 2.5 m span can remain unsupported for about 10 hrs. While, with Basic RMR at 50 – 5 m span can withstand for about a week with the favourable mining conditions. The openings created in the stoping environment will be secured by providing adequate support system. Considering overhand cut-and-fill stoping operation as a man-entry and safety of the persons involved is paramount, 5 m thick crown and rib pillar should be considered and to be left-out during the actual stoping operation. However, considering average width of the ore-body is at 3 m only and considering ore conservation point of view, with suitable support system in place its recovery in judicial and systematic manner at appropriate mining stage could be planned.

Table 4.: Rock Mass Rating at the stoping site at Ukwa mine (Bieniawaski, 1989)

Parameter	Description	Rating
Uni-axial compressive strength	Range 50-100 MPa	7
RQD	Range 50-75	13
Joint Spacing	Av. Range 200-600 mm	10
Joint condition	Occasionally Smooth surfaces/Gouge<5mm/Separation 1-5 mm continuous	10
Ground water condition	Damp	10
Basic RMR Rating		**50**
Fracture orientation rating	Unfavourable	(-)15
Adjusted RMR Rating		**35**

BARTON'S Q SYSTEM

The Q-system was developed for evaluating support requirements in tunnels and caverns. However, it can be applied to mines with good engineering sense. The Q system (Barton et al, 1974) which is based on rock mass quality relies on the following parameters: RQD =55 (for schist rock type with phyllite intrusion), Joint set number (Jn =6), Joint alteration number (Ja=2), Joint roughness number (Jr=1.5), Joint water reduction factor (Jw=0.66), and Stress reduction factor (SRF=1). After applying following relation and putting rating values, Q is determined at 4.5 (Say Q = 5).

$$Q = (RQD/J_n) \times (J_r/J_a) \times (J_w/ SRF) \quad (3)$$

De = Span/ESR = 5/5 = 1 (For temporary mine opening, ESR = 5 and span = 5 m considering full thickness of the orebody). Where, De = Equivalent Dimension, and ESR = Excavation **s**upport Ratio (for temporary mining openings ESR is generally considered at 3-5, while for permanent openings at 1.6 and 1 in the case of intersections). The relationship between the maximum equivalent dimension, De, and the Q value, for a 5 m span (considering full stope width) with determined equivalent dimension at 1 in a rock mass with a Q value equal to 5 falls under the systematic bolting category at 1.0 m spacing. The length of rock bolts for excavation width at 5 m (stope width) with ESR 5 is determined at 2.2 m using relationship: L=2+(0.15B/ESR). The ESR=5 is considered due to the presence of narrow width of the ore-body with mostly average at 3 m and maximum at 5-6 m. The estimated rock bolt support system with length at 2.2 m and at spacing of 1.0 m is valid for stope width varying from 3-6 m also. Maximum unsupported span determined at 15 m with ESR and Q at 5 with following given relationship.

$$\text{Maximum unsupported span} = 2ESR \times Q^{0.4} \qquad (4)$$

Thus, post-pillar of 5 m thick in the case of stope width of 5 m is to be left-out after every stoping span of 15 m at safer side. However, at Ukwa mine mostly average stope width is at 3 m, since, requirement of leaving post-pillars is not found and which is also validated from the numerical modelling studies as presented in below. However, suitable support system as per SSR and DGMS guidelines should be in place to take care of the abutment stresses generated during the actual stoping operation. Also, 5 m crown and rib pillar would be sufficient enough in the form of natural support to be left-out to take care of the abutment stresses generated during the actual stoping operation. However, from the conservation point of view, these pillars recovery could be planned judicially at later stage of the mining with suitable cemented filling and or support system is in

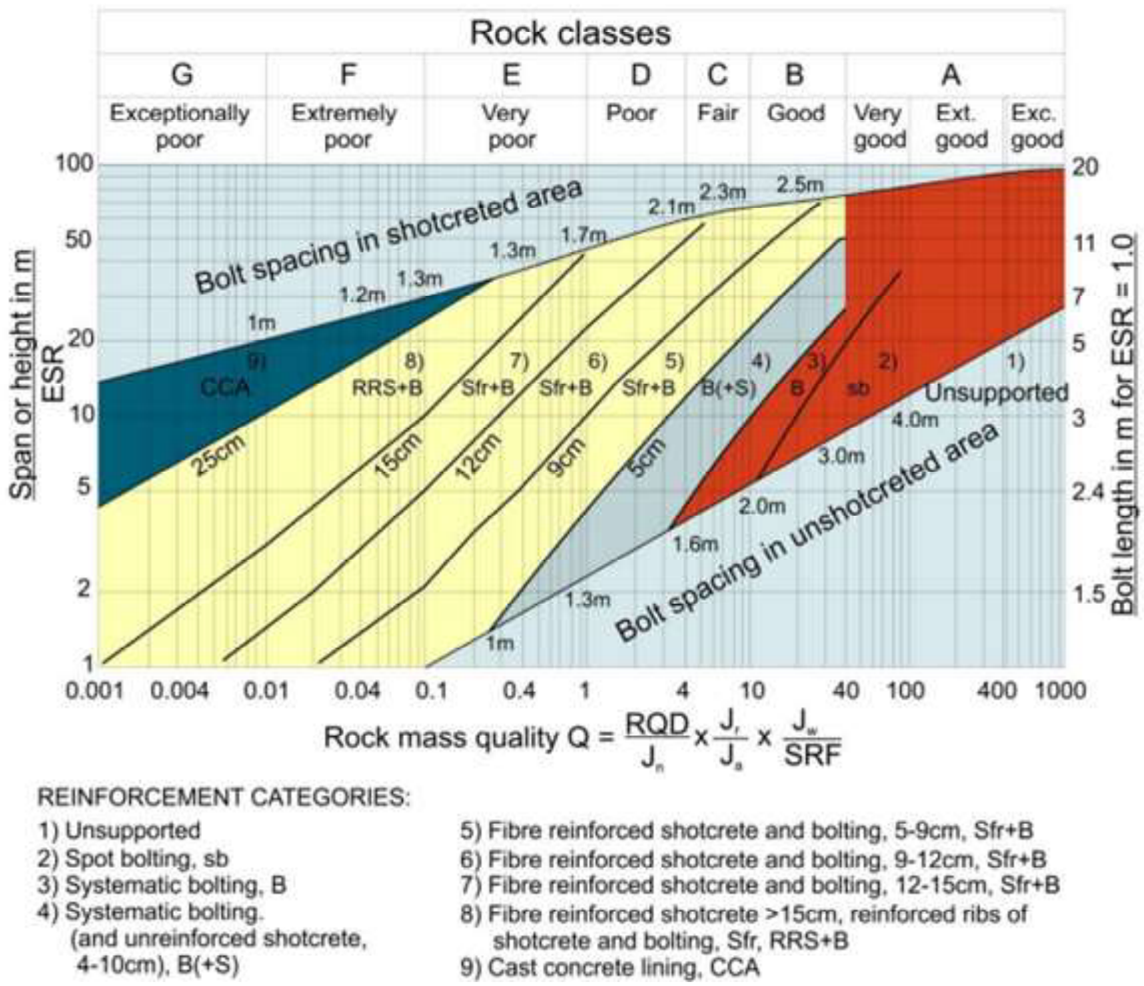

Fig. 1.: Relationship between equivalent dimension and Barton's Q (Barton et al, 1976)

CONCLUSION

In the view the safety of the stoping environment and permanent type of the structures which are under construction, the studies were carried out using empirical approaches like Bieniawaski's RMR, Barton's Q and numerical modelling studies and then estimated support requirement. The application of the various observational, empirical and rock mechanics approaches as well as good engineering sense, the support requirement during the overhand cut-and-fill stoping operation as well as excavation of haulage roadways, cross-cuts and ore-drives is estimated and recommended. The present research with the support recommendations pertain to the stoping operation is being planned and related drivages at the 1650 L. Though, the present recommendations may be applicable in similar kind of rock type in the case of stoping and drivages at the same mine, however, should be applied with caution and good rock engineering sense. It is advised to go for the review of the present recommendations made herewith during the execution of the excavation of the underground openings as and when required and also in the case of any changes in rock mass and working conditions. The instrumentation scheme is also being recommended to monitor the stress and convergence taking place during the actual stoping operation.

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Indian Initiatives on Sustainable Development in Mining

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ABSTRACT

Mining contributes over 2.5 percent of GDP of India and thus holds an important position in Indian economic development. Besides, it is one of the largest job creater (both direct & indirect). With mining is associated some of the problems like its impact on environment, on the society, on the forest eco-system etc. Presently majority of ore/coal production is from opencast mining and this needs large areas to mine, to relocate the villages and forest areas apart from environmental problems. To address various problems in a single most approach has been Sustainable Development'. Although several initiatives have been taken to devise and implement sustainable development approaches in mines, regulations are in place in India to give an emphasis seriously. An attempt has been made in this paper to present the various initiatives taken up for mines in India.

INTRODUCTION

Brundtland Committee Report, was the first initiative to define sustainable development as 'development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs' (WCED, 1987). In 1992, the United Nations, introduced to the world the concept of sustainable development. Viederman (1994) defined sustainability 'as a participatory process that makes prudent use of all its resources, which include natural, human and social capital'.

SUSTAINABILITY OF MINING OPERATIONS

Sustainable mining has been defined by (Tilton 2009) as an oxymoron, since mining depends on non-renewable and depleting mineral resources and, by its very nature, is unsustainable. The basic problem of mining sustainability is that the contribution of mineral development to the regional development is not always commensurate with the huge investment in the mining projects. The key to ensuring sustainability at the local level is an integrated approach for mineral development along with socio economic development of the region (National Mineral Policy, 2008).

In the report by Mining, Mineral and Sustainable Development (MMSD 2002) a wide range of issues covered by a mining project are highlighted. The report indicates that sustainable development requires an equitable sharing of benefits by communities. It is essential to point out here that certain key sustainability issues related to mining should be resolved during the life cycle of a mine before a mine is closed.

ICMM Best Practices which provided detailed guidance to the mining industry on how contribute to sustainable development. Most of these reports utilize and refer to the Brundtland Commission (WCED 1987) where Sustainable–

Exploration: Identify and prove feasible deposits

Site design: Most cost effective mine site design in accordance with legislative requirements & minimisation of societal impacts
Design for Post Mine Closure: Providing on going viability for the community once the operations have ceased
Operations – Operate the mine to minimise environmental and social impacts to maximise economic return.
Closure – Close the mine with minimal negative impacts and leave a positive legacy

Development is defined as the one that: **"... meets the needs of the present without compromising the ability of future generations to meet their own needs."**

This definition encompasses the need to incorporate environmental, economic and social considerations into decision-making; fosters intra generational equity through the elimination of poverty by concentrating the benefits of development in lesser developed areas and to ensure that intergenerational equity exists.

The 10 Principles identified by ICMM for sustainable development that are based on the issues identified in the MMSD are shown in the Table 2.

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Table 2 : ICMM Principles for Sustainable Development

1	Implement and maintain ethical business practices and sound systems of corporate governance.
2	Integrate sustainable development considerations within the corporate decision-making process.
3	Uphold fundamental human rights and respect cultures, customs and values in dealings with employees and others who are affected by our activities.
4	Implement risk management strategies based on valid data and sound science.
5	Seek continual improvement of our health and safety performance.
6	Seek continual improvement of our environmental performance.
7	Contribute to conservation of biodiversity and integrated approaches to land use planning.
8	Facilitate and encourage responsible product design, use, re-use, recycling and disposal of our products.
9	Contribute to the social, economic and institutional development of the communities in which we operate.
10	Implement effective and transparent engagement, communication and independently verified reporting arrangements with our stakeholders.

The projects that have been identified as being successful (see for example Harvey & Nish 2005), Gibson 2005, ICMM Best Practice case studies - have suggested the following aspects as being significant contributions to success:

- Mutual rights and responsibilities
- Capacity building in mining and non-mining related occupations
- Creating a shared vision for regional development
- Strong and visionary partnerships
- Transparent calculation of financial benefits
- Quick win visible projects
- Involvement and capacity of marginalised sectors of the community

UNDP in the year 2018 published a document 'Managing mining for sustainable development; as a part of its Poverty-Environment Initiative in the Asia-Pacific region of UNDP and UN Environment enumerated steps taken in this sector. According to Carvalho (2017) the current mining activities need to reinforce procedures for protection of environment and public health, as it is today easier to see that mining usually brings into the biosphere large amounts of non-targeted chemical elements often with toxic properties to the environment and humans (e.g. radio-elements and toxic metals) and previously neglected.

MINING – SDG

Some of the areas where researchers have laid thrust has been stated include Mine Closure, Cut-Off Grade, Social-environmental impacts, production planning, Mines Safety, Mineral processing etc.

SUSTAINABLE SUPPLY CHAIN MANAGEMENT (SSCM)

Jia, Peng et el (2015) have explained the dominant SSCM practices in the mining and mineral industries with the help of Interpretive Structural Modelling (ISM). Their study uses three different research phases: identification of SSCM practices from the literature, interviews with various department managers of the Indian mining and mineral industries, and a survey conducted within the mining and mineral industries. In this paper, 25 SSCM practices were considered in fewer than six categories. Finally, the approach was applied to fifteen mining and mineral industries in India. The results of this study show that suppliers× ISO14000 certification practice acts as an influential role over the recommended 25 SSCM practices. It is inferred that environmental management certification is therefore essential to increase sustainability performances in Indian mining and mineral industries.

INDIAN SCENARIO

Indian mining and mineral industries started to adopt SSCM practices in their TSCM. But they struggle to identify which practices provide more impact to improve sustainability in their respective industries. This paper presents a study undertaken among 15 mining and mineral industries in India. It identifies the key motivating SSCM practice from the recommended 25 practices under six categories. A result of this study infers that Indian mining and mineral industries have notable awareness.

Analytic Hierarchy Process (AHP) is used to evaluate the competitive priorities of these criteria, and interested organizations can use it as a procedural guidance for Green supply chain management (GSCM) implementation. According to the study undertaken by Shen, L. et el (2015.), it has been found that mining companies have not given the “soft” factors of GSCM adequate attention. This study explores how the “appropriate implementation approach” and “continuous improvement” are the weaker areas of GSCM practice in the case of the Indian mining sector. Hence, mining industries need to focus on these weaker areas and bring necessary improvements to these areas in order to enhance their GSCM performance. They have studied Indian Mining scenario]

PRINCIPLES OF MINING SUSTAINABILITY

Gibson (2012) deliberated on sustainability aspects. Herbertson (2005) had explained sustainability with special reference to Mining. The same is placed at Table 1.

ESG RATINGS

ESG ratings are evaluations of any company’s management performance in environmental, social, and governance (ESG) factors, they provide investors, stakeholders, and fund managers with an understanding of the ESG risks and opportunities associated with a company’s operations. ESG scores take into account a variety factors, including a company’s environmental impact, its social responsibility, ESG disclosures and corporate governance practices.

ESG Rating has been an integral party of corporate governance which uses latest ESG information and tools, in line with their sustainability goals, or regarding socially responsible investing.

ESG ratings work, for example, is with a rules-based methodology that uses publicly reported data to grade company management, business ethics, environmental social and governance, carbon emissions, and social performance, all to point to whether that company is a ‘leader’, ‘average’, or a ‘laggard’. An unexceptional track record on human rights, or poor natural capital management, for example, could pull a company in the ‘laggard’ direction, increasing the company’s exposure to external stakeholders, industry competition, and further analysis.

INDIAN INITIATIVES

Planning Commission of India (presently known as Niti Ayog) has undertaken initial studies in the direction of sustainable development in the mining sector (Mohanty and Goyal, 2012). Daizy and Das (2014) in their study concluded that Indian mining sector have been showing positive signs in embracing the principles of sustainable development that seek to balance economic, social and environmental well being now and for the bright future for mining sector. Recent policy development, government policies, laws and procedures as well as industry behaviour and practices to these principles shall also encourage the reporting efforts in Indian mining sector. Lodhia (Editor) (2018) presented the current issues of mining and sustainable Development. The papers reviewed the current topical issues in mining and sustainable development. Also addresses the changing role of minerals in society, the social acceptance of mining, due diligence in the mining industry, critical and contemporary debates such as mining and indigenous peoples and transit worker accommodation, corporate sustainability matters such as sustainability reporting and taxation, and sustainability solutions through an emphasis on renewable energy and shared-used infrastructure. Bagri et el (2022) dealt on the scenario of the coal industry and analyzed the relationship between

Table 1 : Principles of Sustainability

Sustainability Principle 1 "In a sustainable society, nature is not subject to systematically increasing concentrations of substances from the Earth's crust"	Systematic concentration rises are a strong indication that nature's powerful regenerative capacities have been exceeded. Aligning with SP1 can involve substituting minerals that are scarce in nature with others that are more abundant, using all mined materials efficiently, reducing dependence on fossil fuels and managing problematic elements in closed loop systems rather than by 'dilute and disperse' strategies. It does not mean "no mining", but it does mean that companies engaged in mining or dependant on mined materials have an obligation to avoid dispersion and systematic build up of substances from the earth's crust in the biosphere.
Sustainability Principle 2 "In a sustainable society, nature is not subject to systematically increasing concentrations of substances produced by society"	SP2 addresses the use of substances produced industrially that are foreign to nature. Alignment with SP2 can involve substituting certain persistent and compounds foreign to nature with ones that are normally abundant or break down more easily in nature, using all substances produced by society efficiently, and managing potentially toxic chemicals in closed systems to avoid dispersion.
Sustainability Principle 3 "In a sustainable society, nature is not subject to systematically increasing degradation by physical means"	SP3 is concerned with the physical protection of natural habitats and biodiversity, which underpin the robustness of the regenerative services we depend on from nature. Avoiding long term degradation of nature means drawing on resources from well-managed ecosystems, systematically pursuing the most productive and efficient use both of those resources and land, and exercising caution in all kinds of modification of nature.
Sustainability Principle 4 "In a sustainable society, people are not subject to conditions that systematically undermine their capacity to meet their needs"	SP4 is about avoiding the economic, social and political conditions which undermine the foundations of human well-being and social coherence. This means checking whether our behaviour has consequences for people, now or in the future, that restrict their opportunities to lead a fulfilling life. This includes asking ourselves whether we would like be subjected to the conditions we create. (also referenced as the Golden Rule).

strength, weakness, opportunities, and threats of Indian Coal Mining sector towards Sustainable Development,

INDIAN GOVERNMENT INITIATIVES

The National Mineral Policy, 1993, was an important document to provide legal framework for the mines and mineral sector stipulating provisions for regulation of minerals, followed by its further revision as National Mineral Policy, 2008. In the 2008 policy, for the first time the need for sustainable mining to preserve and augment the exhaustible mineral reserves and optimal utilization of natural resources were highlighted. It established all mining to be undertaken within the comprehensive Sustainable Development Framework, which includes guiding principles for effective closure of mines, with appropriate reclamation/ rehabilitation for maintaining the ecological condition.

SUSTAINABILITY DEVELOPMENT FRAMEWORK (SDF)

SDF for any mining region will primarily focus on sustainability issues that are raised during mine life cycle and after mine closure (Ministry of Mines, 2011). Before enacting the law, Ministry of Mines alongwith Indian Bureau of Mines had taken the various mining companies to roll out SDF. The roll out was held on January 2016 at Sukinda Chromite Mine of Tata Steel. An exclusive Chapter on Sustainable Development in MCDR 2017 has been incorporated. The Rule 35 to 44 is placed below. Kale & Sharma (2020) and Kale et el (2023) have discussed at length the present steps of the central government in the areas of sustainability. Figure 1, explains the environmental regulations of India leading to achieve sustainable development. Mishra and Ganguly (2019) discussed about the legal and regulatory framework, technologies and best process practices prevalent in Indian mines to achieve the goals of sustainable Mining (Figure 2).

SUSTAINABLE MINING

MoeFCC Guidelines

2016 : Sustainable sand mining management guidelines, was issued by MoEFCC. The main objective of this Guideline has been -

- To ensure that sand and gravel mining is done in environmentally sustainable and socially responsible manner.
- To ensure availability of adequate quantity of aggregate in sustainable manner.

Figure 2 : Environmental Regulations in the Indian mining sector

- To improve the effectiveness of monitoring of mining and transportation of mined out material. • Ensure conservation of the river equilibrium and its natural environment by protection and restoration of the ecological system.
- Avoid aggradation at the downstream reach especially those with hydraulic structures such as jetties, water intakes etc.

- Ensure that the rivers are protected from bank and bed erosion beyond its stable profile.
- No obstruction to the river flow, water transport and restoring the riparian rights and instream habitats.
- Avoid pollution of river water leading to water quality deterioration.
- To prevent depletion of ground water reserves due to excessive draining out of ground water.
- To prevent ground water pollution by prohibiting sand mining on fissures where it works as filter prior to ground water recharge.
- To maintain the river equilibrium with the application of sediment transport principles in determining the locations, period and quantity to be extracted.
- Streamlining and simplifying the process for grant of environmental clearance (EC) for sustainable mining.

2019 : NATIONAL MINERAL POLICY

The National Mineral Policy approved in February 2019 incorporates the public trust doctrine, inter-generational equity principle, and ownership of natural resources as commons. It holds the State as the trustee on behalf of the people to ensure future generations receive the benefit of inheritance calling for stringent regulations to ensure environmentally sustainable mining practices incorporating social and economic considerations. Some of the changes made during 2017 till 2023 have also been added in these Rules (in italics).

Mukhopadhyay (2016) gave an overview of Indian mining sector, while, Jakati (2023) reported about the sustainable Growth of Mining Industry of Goa and its environmental and concluded that *'at the beginning mining industry appeared to be beneficial to the Goan economy, with time it proved that it caused more damage to the society and environment. Mining activity is ephemeral and does not compensate for all the damage caused. It would need Goa, years and years to recover from the damage'*.

Indian Council of Forestry Research and Education (ICFRE), Dehradun(2018) in compliance of the Action Taken report on the 'Memorandum of Action taken' on the 'First report on illegal mining of iron and manganese ores in the state of Jharkhand' of Justice M. B. Shah Commission of inquiry, submitted to the Government, the MoEF& CC, vide its letter F.No.11-65/2014-FC, dated 23rd September, 2014,prepared 'Management Plan for Sustainable Mining (MPSM) and Delineation of mining zones and Conservation Area/ No mining zones in Saranda and Chaibasa in Singhbhum District, Jharkhand' incorporating the carrying capacity study also of the Saranda Forest Division in the West Singhbhum District, Jharkhand to suggest annual capacity for iron ore production.

EFFORTS OF CENTRE FOR SOCIAL AND ECONOMIC PROGRESS (CSEP)

The **Sustainable Mining Attractiveness Index**, constructed for Jharkhand by the Centre for Social and Economic Progress, provides stakeholders with a holistic understanding of the potential of mineral resources-led development in the state; identifies factors that encourage and discourage mining investments; suggests government-led policy actions that enable sustainable mining jurisdictions; and provides mining companies benchmarks for guiding investment decisions.

The Index has been constructed by evaluating the 24 districts of Jharkhand based on various secondary data normalised and aggregated under five pillars: (1) mining potential and performance; (2) socio-economic status; (3) policy and governance; (4) infrastructure; and (5) environment. The scores of the five pillars have been averaged to give each district a final sustainable mining attractiveness score and rank (Index).

SDF Samatha Judgement (Ministry of Mines, 2011)

The Samatha Judgement on SDF, recommended following provisions:

- Mining in Schedule V areas [tribal areas] should not be allowed without the participation of the local people.

- 20% of net profits to be set aside as a permanent fund for the establishment and maintenance of water resources, schools, hospitals, sanitation and transport facilities, reforestation and maintenance of ecology.

- It suggested to the state government to organize cooperative societies solely composed of scheduled tribes, to undertake mining operation in schedule V areas Hon'ble Supreme Court of India in 2005 had set up a high level committee to review the status and explore the potential for increasing investment in Indian mining sector (Ministry of Mines, 2011).

The "Hoda Commission" has recommended that apart from introducing best practices in implementation of environment management, there is also a need to take into account the global trends in sustainable developments. The High Level Committee specifically studied the impact of mineral development with the need to develop principles in mining, best practices, and reporting standards which may be measured objectively. The committee emphasized the need for Sustainable development framework for the Indian Mining Sector.

DIGITISATION

Every industry segment has augmented the operations and evaluation plans with the help of digital intervention. In this respect the Industry 4.0 technologies provide critical perspectives for future innovation and business growth. Technologies like Artificial Intelligence (AI), Internet of Things (IoT), Big data, Machine Learning (ML), and other advanced upcoming technologies are being used to implement Industry 4.0. The Industry 4.0 technologies have integrated the crucial interrelationships through advanced technologies for understanding the impact on the environment positively. In the age of Industry 4.0, manufacturing is tightly interlinked with information and communication systems, making it more scalable, competitive, and knowledgeable. Industry 4.0 provides a range of principles, instructions, and technology for constructing new and existing factories, enabling consumers to choose different models at production rates with scalable robotics, information, and communications technology. In the mining sector also it had immense application scope. Javaid, Md et el (2022), have identified and discussed about twenty major applications of Industry 4.0 to create a sustainable environment.

CONCLUSION

Various efforts made by the Govt. of India and various mines have infused new method of mining so as to ensure 'sustainability' components. The good beginning made by every large mining companies are laudable but much attention is required for the un-organised sector mines.

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