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Efficacy of different vegetation methods for stabilization of iron ore fines dump in a surface iron ore mine

The disproportionate increase in the production of iron ore in Odisha has resulted in the accumulation of large quantity of fines ore. Although literature suggests stabilization of dumps using re-vegetation methods, the most effective method of stabilization is still in question. Hence this study was conducted to examine the effectiveness of the three different vegetation methods at fines dump namely, vegetation by coir matting, vegetation by local species and vegetation by grass. This study adopted in-situ jack shear test to find out the most efficient vegetation method for the stabilization of iron ore fine dumps. This study used a customized shear box having a dimension of 0.15m × 0.15 m ×0.15 m, which was specifically designed and fabricated to evaluate the mechanical stability of vegetated fines dump by different vegetation methods. The analysis of field data, graphical presentation and cost analysis has helped us to conclude that the plantation of local species has increased the mechanical stability of fines dump in comparison wth the plantation of grass or coir matting. Further, local species such as Karanj (Ponganna Pinnata), Shisham (Dalbergia Sissoo), Neem (Azadirachta India), Sal (Shorea Robusta), Kendu (Diospyros Melanoxylon), Amla (Phyllanthus Emblical) Jamun (Syzgium Cumini), Banyan (Ficus Benghalensis) and Krishnachura (Delonix Regia) were estimated to be more cost-effective for stabilization of fines dumps, with a possibility of extending its role towards maintaining long term stability, when compared to other methods.

Keywords: Fines dump, re-vegetation, coir matting, local species, grasses, mechanical properties.

1. Introduction

In any country, iron ore mining occupies a focal point of all mining activities. Experts have predicted that the Indian iron and steel industry shall become the second largest producer of steel globally by the end of the year 2020, owing to the industry's exponential growth over the last 15 years. The compound annual growth rate (CAGR) of 7.45% in the production of steel from 2011 to 2015 is significant (IBEF, 2016). Elimination of large quantities of waste or overburden or low grade iron ore and the production of low grade fines ore, coupled with their emplacement as external fines dump, comprise the functioning of the surface iron ore mines. Owing to the low availability of agglomeration plants, the rate of fines consumption is comparatively lower than the amount produced. Thus, the fines are required to be stacked as fines dumps at designated places.

In India, the fines dump causes environmental and ecological problems as an estimated 600 million tonnes of iron ore fines dumps are accumulated over a vast area. During the rainy seasons, these fines get gully erosion, get washed away and affect agricultural fields and water bodies. Hence, these fines dumps need to be assessed and stacked for a longer period. The available technology must be employed to form, stabilize and maintain such low grade fines dumps.

A substantial increase in the rate of accumulation of low grade fines materials and efforts to minimize ground cover area has resulted in greater height of dumps in recent years. Consequently, it has given rise to the danger of waste dump failures and various associated environmental problems (Campbell, 1992). The fines dump occupies large vast of land, that loses its original use and quality (Bradshaw and Chadwick, 1980). Therefore, the selection of stabilization technique for the fines dump should always be an integral part of the surface iron ore mine (Caldwell and Moss, 1981; Chaulya et al., 2000; Khandelwal and Mozumdar, 1987).

The dump stabilization methods can be classified as (i) mechanical aspects (rock bolting, netting, geosynthetics etc.) and (ii) re-vegetation (grass, shrubs and local species). Mechanical methods yield immediate result in dump stop stabilization and short term effect in the enhancement of dump erosion control. However, over the time it becomes increasingly weaker. On the contrary, re-vegetation is less

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effective initially but becomes progressively more effective over the period of time (Menashe, 1998; Sidle, 1991). Re-vegetation is the most widely used techniques in mines for controlling erosion, stabilizing dump slopes (Akers and Muter, 1974), and sustaining the ecological equilibrium in the area (Jorgensen, 1994).

Cohesion and angle of friction are two of the most important factors in the dump slope stability analysis. The low grade of processed fines material is of low shear strength. However, it gets compacted over a period of time and its shear strength gradually increases up to a limit depend on its physical properties. Therefore, the analysis of dump slope stability requires the assessment of shear strength with reasonable accuracy.

In the present study, the coir matting, plantation by grass and the local (host) plants, – Karanj (Ponganna Pinnata), Shisham (Dalbergia Sissoo), Neem (Azadirachta India), Sal (Shorea Robusta), Kendu (Diospyros Melanoxylon), Amla (Phyllanthus Emblical) Jamun (Syzgium Cumini), Banyan (Ficus Benghalensis) and Krishnachura (Delonix Regia) were used for re-vegetation at fines dumps in a surface iron ore mine. The present study deals with the efficacy of different vegetation methods for stabilize the fines dump in a surface iron ore mine in India and for providing long term protection of environment that gets affected due to mining.

2. Study site

2.1 Location and description

The Thakurani Iron Ore Mines, Block-B of Sarda Mines Private Limited is a large capacity mine in the Indian state of Odisha that has been in mining activity since 2001. The mine is located in village Sayabali , Balita and part of Thakurani Reserve forest of Champua Range, Keonjhar Forest Division lying between longitude 85º25' E and latitude of 22º04' N. The fines dump slope area has been selected for re-vegetation and divided into three sections for different vegetation methods such as coir matting, plantation by grass and local species to knowing the efficacy of vegetation. Fig.1 depicts the topographic view of the Thakurani Iron Ore Mines.

2.2 Climate

The area surrounding mines experiences four seasons, namely, summer, monsoon, winter and spring seasons. Spring season is short lived. Summer season is generally hot and dry spanning from the start of April to the end of June with temperature ranging between 40°C and 45°C. The area experiences moderate rainfall, from 135 to 325 mm/month in July, August and September with an average annual rainfall of 1350 mm/annum. December and January are generally considered as winder months when, minimum temperature comes down to as low as 4°C. The rainfall of the last four years has been depicted in Fig.2.

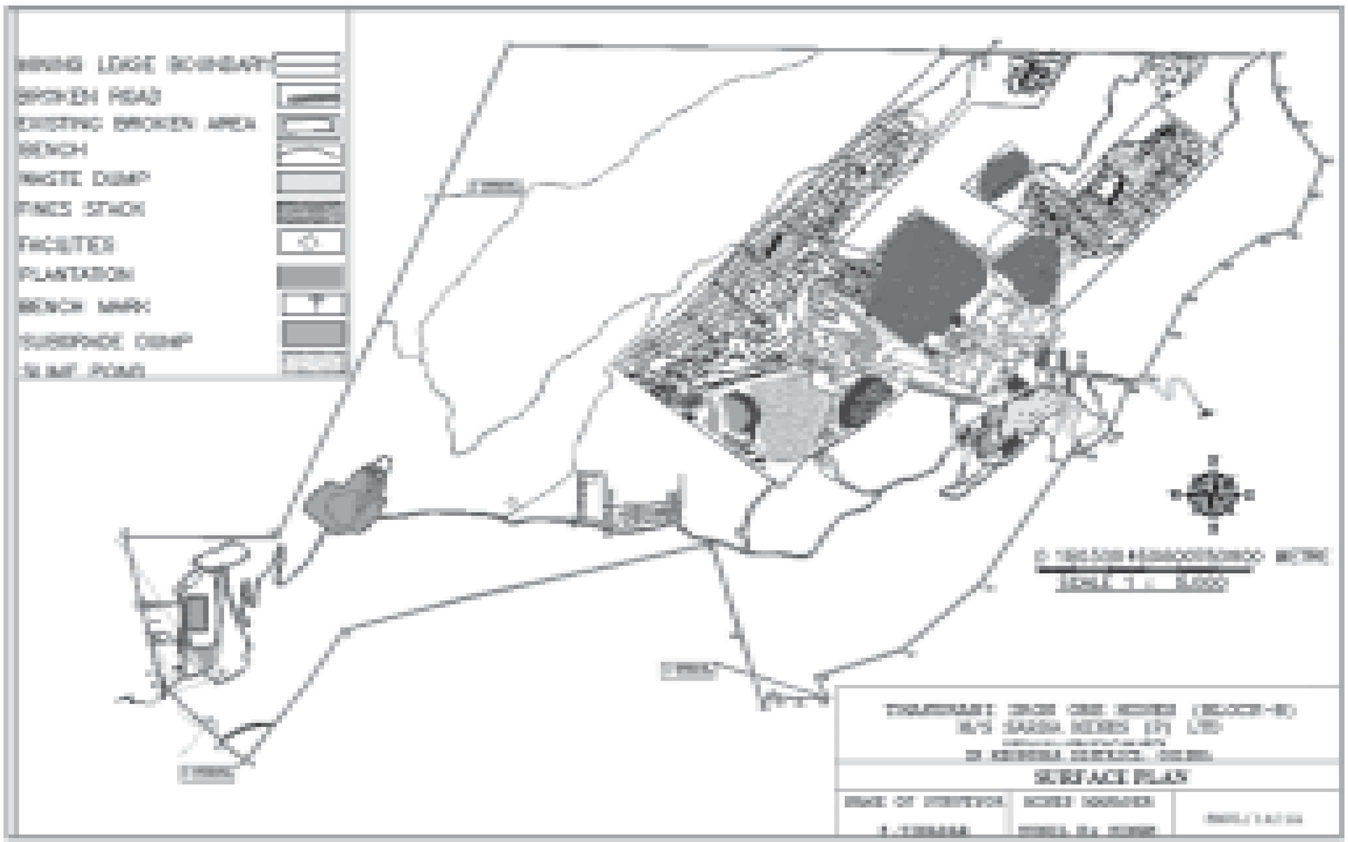

Fig.1 Topographic view of iron ore mines of Sarda Mines (P) Ltd, Barbil

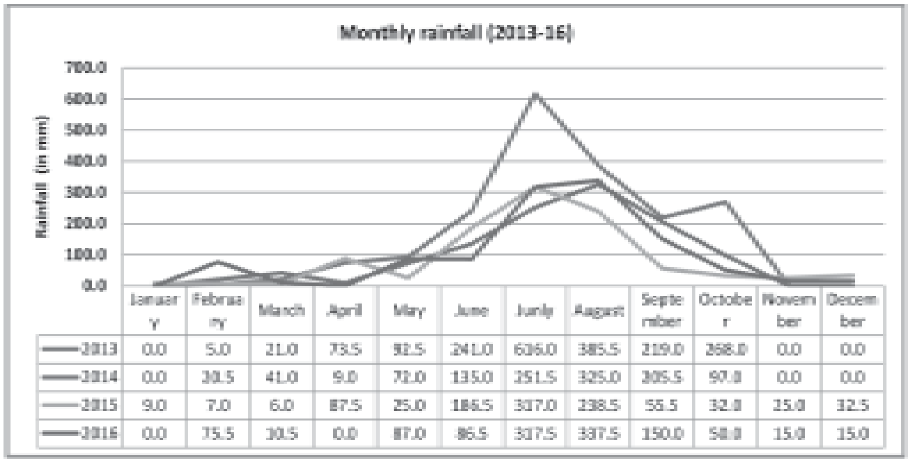

Fig.2 Monthly rainfall of last four years during the period 2013 to 2016

2.3 Geology and fines dump material

The site is located at Thakurani pahar, representing a part of the northern area of the eastern limb of the main "horse shoe" shaped synclinorium and is situated between Noamundi and Joda. The litho-units of the area comprise iron ore/banded hematite jasper (HHJ) or shale, volcanic, sandstone and granite gneiss. The lower shale formation at the north-eastern end of the eastern limb of the synclinorium of Noamundi basin (Banerji, 1977), is mainly composed of a number of acidic and basic flows which have been modified into bleached clayey shale, and sometimes into splintery banded shale. The upper shale is banded in nature with lenses of green chert, altered tuffs and dolomite beds (Murthy and Ghosh, 1971).

The fines dump material consists of low grade hematite iron ore fines. The granulometric compositions of fines dump is depicted in Table 1.

Table 1: Granulometric composition of fines dump

Fraction size (mm)	Percentage fractions (%)
>10	02.24
10-08	05.10
08-06	11.53
06-04	23.65
04-02	22.80
02-01	12.77
< 1	21.91
Total	100

3. Materials and method

3.1 Different methods of re-vegetation

The fines dump area has been selected at the Thakurani iron ore mines for the implementation of different vegetation methods in order to determine the efficacy of these methods for the stabilization of fines dump.

3.1.1 Coir matting

The term coir refers to the fibrous substance that forms the dense mesocarp (median layer) of the coconut (Cocosnucifera L.). The long coir fibers are removed from the husk of the coconut and utilized in the manufacture of industrial products (Balick and Beck, 1990), such as coir mats and netting. From the perspective of re-vegetation, coir matting is used to trap sedimentary residues, safeguard wetland shores and stream banks from erosion, and to offer a stable substrate for the establishment of plants. A coir mat is a form of crude erosion control blanket (Fig.3).

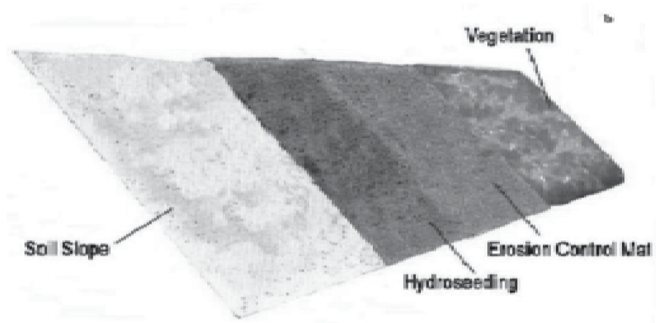

Fig.3 Coir matting process (Lyer and Korulla 2009)

Pre-seeded coir mats can be utilized to guard overburden/ waste dumps, high walls, fly ash dumps, etc. In coal mines, the use of coir matting has been found to be effective in stabilizing overburden dumps (Lyer and Korulla, 2009; Maiti and Saxena, 1998; Maiti and Maiti, 2014). However, their effectiveness in the mines of the Bonai iron ore range is yet to be validated.

3.1.2 Plantation by grass

Vegetation by grasses was first developed for soil and water conservation in farmlands. The usage of various grass such as vetiver, lemon and kashi grasses for slope protection, reinforcement of embankments and cuttings outside of farmlands is known since the early 1900's in the West Indies and South Africa (NRC, 1993), Brazil (Grimshaw, 1994), Fiji (Truong and Gawander, 1996), etc. Various studies have been carried out on the uses of vetiver grass for stabilization of dump slopes (Greenway, 1987; Coppin and Richards, 1990; Gray, 1994; Mukherjee, Goswami, Banerjee and Pathak, 2015).While the vetiver grass finds a good application in agricultural lands, the unique morphological, physiological, and ecological characteristics of vetiver grass makes it more usable for environmental protection.

3.1.3 Plantation by local species

Vegetation by local species at fines dump is one of the strong options for dump slope stabilization and control of soil erosion. The roots of grasses and shrubs (smaller plants) are not capable of going deep into the soil and thus, their overall effect on dump slopes is inconsequential. However, they do perform slope stabilization by anchoring the dump slope's upper soil layer. Hence, from the perspective of dump slopes, small plants are not believed to significantly improve the factor of safety (FoS). Nevertheless, they are perceived to be effective for initial stabilization of dumps. While shrubs strongly strengthen the dump stability in the preliminary stage itself, grasses rapidly bind the upper surface (Rai and Shrivastava, 2014). Certain local plant species, such as Neem, Amla, Shisham, Karanj, etc., have strong roots and thus can penetrate deeper into dumps leading to enduring stability. The roots of these plants bind to the dump material resulting in a composite material of high shear strength. Even a moderately-sized Shisham tree is capable of binding the mine dump's upper layers and thus substantially improving the FoS. Moreover, it has been observed that in such cases, with respect to time, as the plants grow there is a corresponding increase in dump slope stability (Table 2).

TABLE 2: IMPROVEMENT IN FACTOR OF SAFETY WITH DIFFERENT AGES OF PLANTS

	Age of plants (Shisham)	Factor of safety
1	Without vegetation	1.25
2	1 year	1.26
3	Two and half year	1.31
4	4 years	1.46
5	5 years	1.58

The local (host) plants, namely, – Karanj (Ponganna Pinnata), Shisham (Dalbergia Sissoo), Neem (Azadirachta India), Sal (Shorea Robusta), Kendu (Diospyros Melanoxylon), Amla (Phyllanthus Emblical) Jamun (Syzgium Cumini), Banyan (Ficus Benghalensis) and Krishnachura (Delonix Regia) were selected and re-vegetated at fines dump slope in a surface iron ore mine along with vegetation by coir matting and grasses during the month of December 2014.

3.2 IN-SITU JACK SHEAR TEST

The design and fabrication of the field (in situ) sample instrument which is used to determine the shear strength has been done at the different location at vegetated fines dump. The equipment consists of two components; shear box and measuring device. The cubical sample shear box was made of iron sheet having the thickness of 0.005m and with dimensions of (0.15m × 0.15m × 0.15m). An iron plate, which has the similar size of the internal dimensions of shear box, was placed at the top of the sample. The use of this iron box is to apply normal load on the sample. The horizontal force was applied by the hydraulic ram and load failure was measured by a load cell. Fig.4 describes the line diagram (plan and elevation) of the in situ jack shear box (Rai and Shrivastva, 2010).

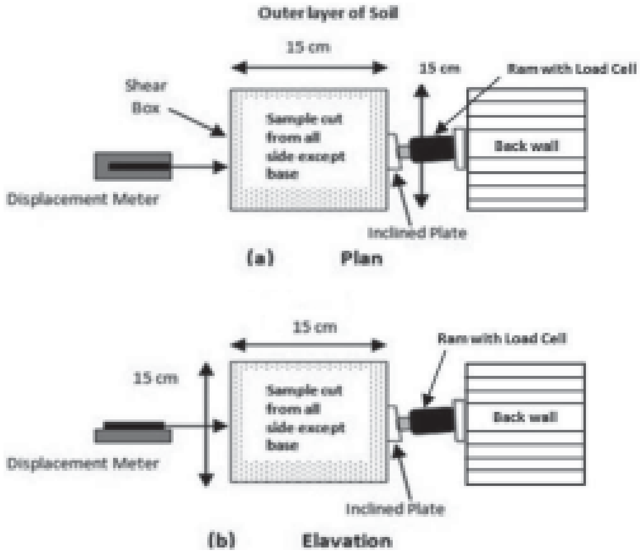

Fig.4 Line diagram of field (in situ) shear box instrument

The area for complete set up of filed (in situ) shear test was marked on the dump surface. Cut a trench of depth 0.15 m around the sample shear box and remove the muck with the help of small hand equipment. Then place the shear box in the trench with the help of a small hand held equipment and wooden pieces. Thus, a sample size of 0.15m × 0.15m × 0.15m was prepared.

It was then covered all around with the shear box as shown in Fig.5. At one end, place an inclined iron plate along the wall of the trench (which supports the ram). The hydraulic ram was fitted between the inclined iron plate and one end of the inclined plate of shear box. Force was applied against the normal load with the help of hydraulic jack and the generated shearing resistance was noted down. The debris of sheared sample along with the testing equipment was removed after completion of testing. Twenty one samples have been taken at different location (top of dump as well as slope site) in fines dump for representing the whole site in respect of vegetation by local plant as well as vegetation by grass at fines dump.

4. Experimental results and discussion

Cohesion and angle of friction were selected as in situ field test parameters to determine the mechanical stability of fines dump after the re-vegetation. In this study, re-vegetation was tried with local species and grass as they are easily available and suitable for local climate, besides having good binding capacity. The results of in-situ tests at fines dump material with respect to different vegetation methods are presented in Table 3.

The shear (jack) test results demonstrate the increased shear strength properties of the re-vegetated dump after local species and grass vegetation. From the results, it is evident that the cohesion of the soil properties has increased after local species (120 KPa) and grass (106 KPa) vegetation.

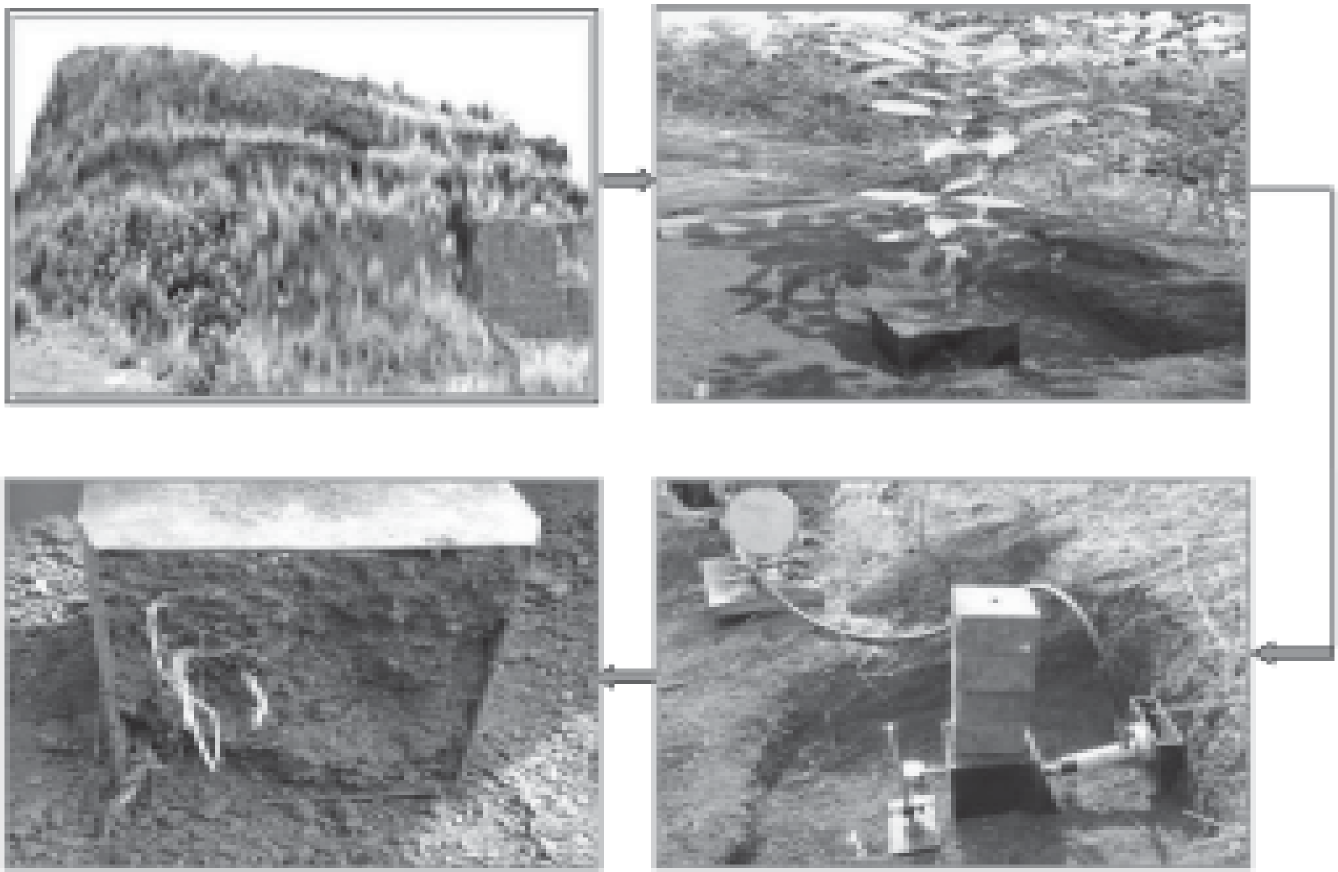

Fig.5 Field arrangement of in situ Jack shear box instrument at fines dump

However, local species could increase the cohesion by 34% as compared to only 16% by grass. Similarly, an improvement was found in angle of friction too, where in the fines dump without re-vegetation, the angle was 19°, while it was increased to 23° for local species and 21° for grasses. The results suggest that overall re-vegetation could bring about an improvement in the shear strength, though local species were found to be better than grass.

The shear strength increased by the local species could be attributed to the role played by plant roots in increasing the increase of the shear and pulling out stress on the soil (Kalilnejad et al., 2012). The roots of local species could be better in increasing the mechanical reinforcement of the dump material, thus enhancing the shear strength and cohesion of dump materials over the tensile stress. In addition, the level of mechanical action depends on root density, depth of root penetration and strength of local species (Greenway, 1987; Hall et al., 1994).

Further, the intricate root system of local species could perform hydrogeological action to increase the dump stability by regulating interception of rain water and evapotranspiration, consequently reducing pore pressure (Hussain, 1995). Mechanical action, on the other hand, refers to the reinforcement of the dump material by the roots and enhancement of the shear strength of dump material. This action is closely related to root density, depth as well as strength of local species (Greenway, 1987; Hall et al., 1994).

The outcomes of field (in-situ) test at fines dump material in respect of different vegetation methods are presented in Table 3.

Further, the outcomes and the efficacy of different vegetation methods for stabilization of fines dump in a surface iron ore mine are depicted in Figs.6 to 9. From the visual representation it is evident that local species were better than vegetation with grass and coir matting. Vegetation with local species demonstrated a more or less uniform coverage on the dump; on the other hand, the grass vegetation was not well spread and was also accompanied by cracks, failures in terms of caving in and gully erosion. Coir matting had much adverse impact on the fine dumps. A complete dump failure was observed suggesting that coir matting could not be good solution unless it is further investigated for its strengthening. Thus, the studies has shown that re-vegetation with local species would be more beneficial than with grass or coir matting.

Costing is a major factor that needs consideration in the mining industry. The cost incurred during the implementation of different vegetation methods at fines dump in a surface iron ore mine is depicted in Table 4.

TABLE 3: OUTCOMES OF FIELD (IN-SITU) SHEAR TEST.

Year	Field test (in-situ) parameters	Measurement unit	Fines dump without vegetation	Re-vegetated fines dump	
				By local species	By grass
1.5 years	Cohesion	KPa	78	86	82
	Angle of friction	Degree (°)	19°	20°	19°
2.5 years	Cohesion	KPa	80	106	94
	Angle of friction	Degree (°)	19°	21°	20°
3.0 years	Cohesion	KPa	82	120	106
	Angle of friction	Degree (°)	19°	23°	21°

TABLE 4: COST ANALYSIS OF DIFFERENT VEGETATION METHODS

	Activity	Vegetation by local species (In Rs. per square meter)	Vegetation by grass (in Rs. per square meter)	Vegetation by coir matting (In Rs. per square meter)
1	Cost of material	50	74	95
2	Earth work-preparatory work for plantation (cost of engaged manpower)	20	25	42
3	Planting cost (manpower cost)	6	10	15
4	Watering cost	4	5	5
5	Fertilizer cost	4	4	4
6	Maintenance cost at the interval of six month (up to 2 years)	2	5	7
	Total cost per square meter	86	123	168

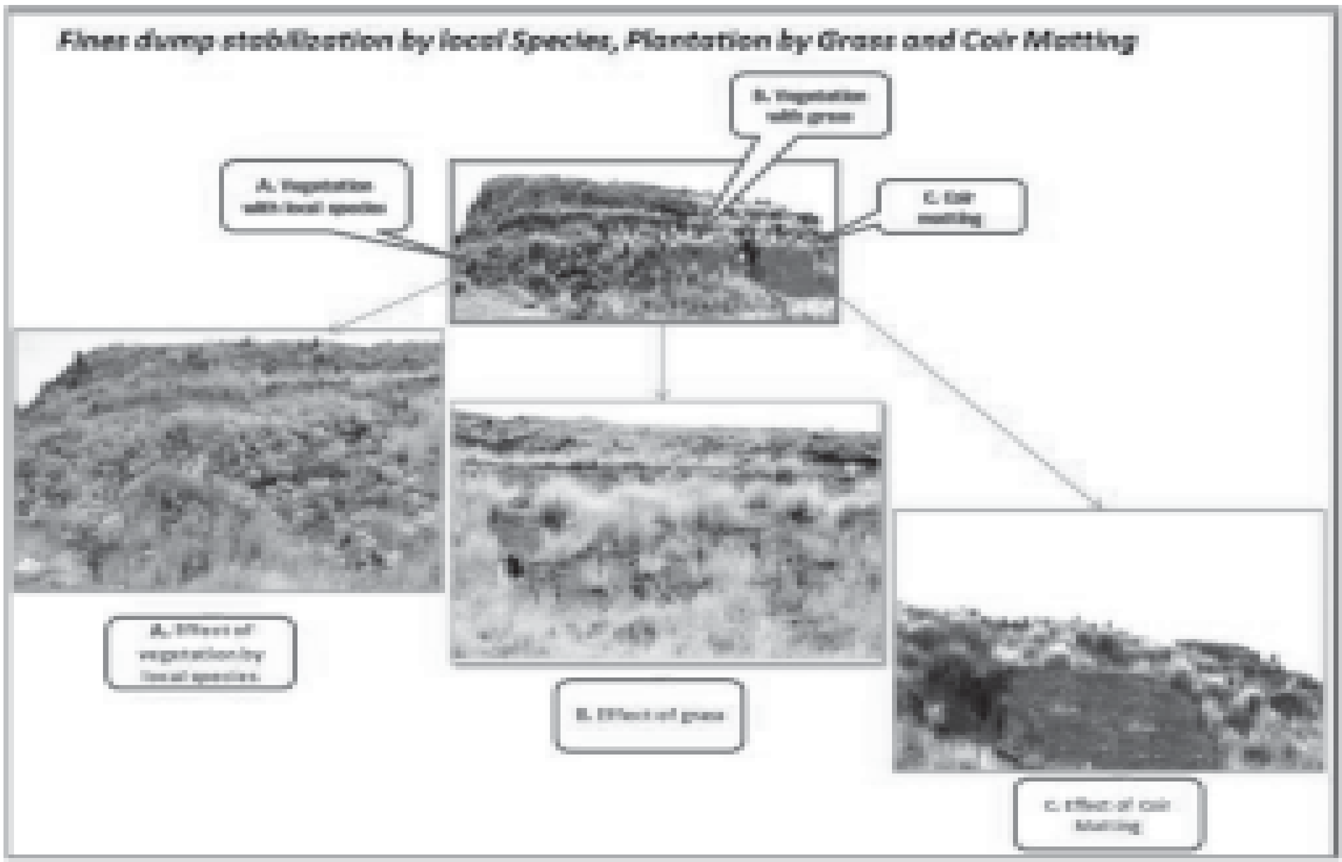

Fig.6 Fines dump stabilization by different vegetation methods

Fig.7 Effect of vegetation by local species at fines dump

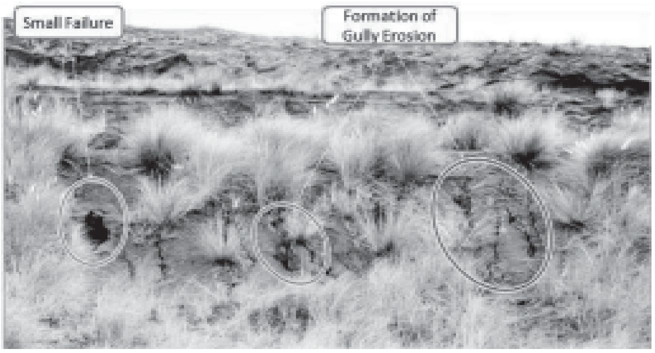

Fig.8 Effect of vegetation by grass at fines dump

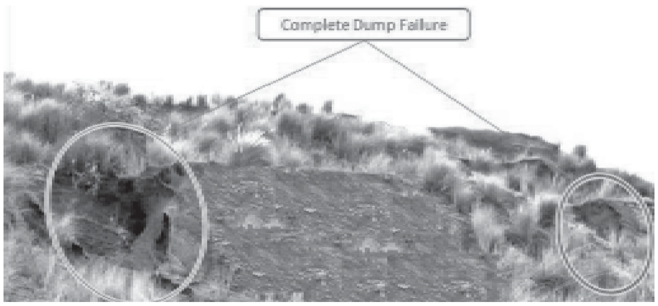

Fig.9 Effect of vegetation by coir matting at fined dump

From the table, it is clear that re-vegetation using local species is most cost-effective in comparison with grass or coir matting. A substantial difference could be observed, especially in cost of material, preparatory work, plantation and maintenance cost, among the methods. Thus, the other expenses, such as watering cost and fertilizer cost remained the same for all the three methods. The cost of grass and coir matting for re-vegetation was 70% and 100%, respectively, higher than the use of local species, thus proving that local species is cost-effective than grass and coir matting.

5. Conclusions

The study adopted in-situ field test to find out the efficacy of the three vegetation methods for dump stabilization at fines dump. From the results and graphical presentation, the plantation by local species was found to be more effective for fines dump stabilization as compared to the plantation by grass and coir matting. It is always eco-friendly, most acceptable, cost-effective and protects slopes against the surficial erosion and shallow mass movement. The growth of local species is more due to its suitability with local climate and soil. Further, it will create the same ecology and habitation of local animals and birds as well as it gives the more opportunity to use of end product. From the above analysis, it is evident that the cohesion, angle of friction and binding properties are improved significantly in the case of vegetation by local species which results in minimizing the formation of gully erosion and failure of dump. Also, the vegetation using coir mating is the least effective method among these three methods because of its poor ability to stabilize fines dump which is a result of its poor binding property. Another disadvantage of this method is its high cost compared to other two methods. The major advantage of the vegetation using grass is its ability to bind the upper surface quickly. However, the gully erosions and the poor failure stabilization ability and comparatively higher cost makes it less attractive. Thus, in conclusion the study and the result derived from it gives the clear and comprehensive picture about the efficacy of the three vegetation methods which are used for the fines dump stabilization.

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