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Comparative characterization of overburden material vis-a-vis sand as an alternative for stowing in underground mines

The results discussed in this paper highlighted a comparative experimental study of overburden material (OBM) from mines and natural sand used as stowing/ backfilling material. The study includes some significant parameters related with physical properties like particle size, dry unit weight, porosity, permeability etc. The change in pressure gradient on slurry transport behaviour of OBM and sand for increasing concentration range of 0.04, 0.10 and 0.30 by volume (C_v) for 37.5 mm circular pipe loop have been evaluated experimentally and compared. The linear expressions related with this pressure gradient for both slurry mixtures have been presented using multiple regression of data based on experimental observations. Water percolation characteristic after placement of slurry mixture at deposition stage for concentrations 0.25 and 0.50 by volume (C_v) also have been evaluated experimentally and compared.

Preamble

Large underground space left out after mining operations creates subsidence problems affecting ground stability. Thus, to provide ground supports to minimise the land subsidence problems and mine safety aspects, backfilling is the valuable part of mining (Kesimal et al. 2002, Barret et al. 1978). The backfilling of underground voids improves the stability, enabling more efficient mining of the surrounding areas (Grice T 2001).

Hydraulic fill is one of the most commonly used mine-fill technique, which ultimately provides the stability. In hydraulic fill method river sand is widely used as a stowing material, as it is easily available and economically feasible and the most important is its geotechnical properties. Stowing material is generally hydro-transported to its desired destination to fill up the voids and the carrier is allowed to drain out.

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Sand is getting depleted day by day due to its huge use in infrastructure works as a main constituent of concrete (Prashant et al. 2010). Maharashtra regulatory restrictions on sand mining have lead to unavailability of sand for backfilling or stowing purpose. Hence unavailability of river sand for backfilling mine voids is a major concern and mine operators and planners are emphasizing on developing an alternative stowing material to river sand. Some of the common types of materials which can be used for backfilling other than sand are waste overburden (OB) rock in crushed form, mail tailings, quarried rock and gravel.

Huge quantity of overburden material is generated in opencast workings of the mines of MOIL (Manganese Ore India Limited). Use of these OB materials for backfilling/ stowing may found to be useful for mining industries to recycle the material and reduce the environmental impact, thus saving of the land used for dump creation. OB dump is considered as a major constituent to the ecological and environmental degradation as soil erosion and environmental pollution (Yaseen et al. 2012). Most of the OB material is disposed temporarily over valuable land mass, which inevitably requires planning and control to minimise their negative impacts over environment (Barapanda 2001). The transportation cost will be also minimized as the filling material will be available in the close proximity of mine.

Alternative material for backfilling in underground mine void is selected on the basis of its physical and geotechnical properties and flow characteristics. In view of these, It was proposed to carry out technical investigation into the feasibility of developing a strong alternative filling material in place of sand i.e. overburden material for stowing purpose in MOIL mines. While choosing a hydro-transported stowing material in form of slurry mixture, it is governed by pipeline parameters, liquid parameters, solid parameters and system parameters e.g. mixture flow velocity, volumetric concentration, particle size, pressure gradient etc., particle size is one of the important physical property and pressure drop reduction while transport of slurry for overburden material in comparison with sand have been highlighted in this paper as discussed in Govier G W and Aziz K (1972) and Wasp et al.

(1977). The experimental analysis for slurry mixtures of sand and OBM carried out with increasing concentrations. This effect is referred to as discussed in Abd Al Aziz and AI Mohamed H I (2013). Stephen H S and Steven R A (2002) indicated that hydraulic gradient reduction effect resulting from phosphate clay added to sand and water slurries increases with concentration, decreases with particle size. Kazanskij et al. (1974) carried out experiments with 100 mm pipeline found that pressure drop reduces at lower velocities. This approach is utilized in this study to evaluate the flow characteristics (velocity, hydraulic/pressure gradient etc.) for pure water, sand and OBM slurries. Two-layer model of Gillies et al. (1991) to predict the pressure drop for coarse slurry mixed with fine fly ash slurry was also referred for experimental analysis.

Along with particle size analysis some additional geotechnical properties like dry unit weight, specific gravity, void ratio, porosity etc of OBM and sand have been compared in view of stowing material. Water percolation characteristics of stowing material need to be studied for effective placement of slurry at deposition stage. Water percolation characteristic is mainly associated with permeability (hydraulic conductivity) which can be defined as the ease with which water can flow through a soil.

The experimental data in the present study refers to overburden material (OBM) from Dongri-Buzurg mine and the source of natural sand is Pench river, Nagpur (MS).

Physical characteristics of stowing materials used in this study

Particle size analysis

There is a significant importance of grain size over geotechnical assessment of filling material. Backfilling material, which contains well-graded particles, should offer more resistance to displacement and settlement than one with uniformly graded particles. Kesimal (2004) found that particle size distribution (PSD) analysis is one of the most important parameters for backfilling materials. Maximum grain size of a grain used in filling should be less than 1/5th of the pipe bore to limit the critical velocity of flow in pipe (Prashant et al. 2010). It has been observed that the presence of fine grained sediments within coarse particle slurries results in a reduction of power required for pumping the slurry to disposal. The required pump pressure to transport slurries in pipelines and inject them into voids and cracks is a function size distribution of aggregates with some important parameters (Alehossein H 2012). The mechanisms responsible for hydraulic gradient reduction effect are not well understood or quantified. Limited studies have verified that fine sediment concentrations as low as 6% of the total solids volume reduces the hydraulic gradient in pipelines. The maximum backfill grain size is generally limited by material transport restrictions.

ASTM D 422 - Standard test method for particle-size analysis of soils was referred for analyzing the data .The test samples of OBM were collected from various open cast sites of Dongri Buzurg mine. These samples are crushed in crushing machine.

This mixed test samples are selected for PSD analysis. A set of sieves with aperture sizes 212 μm, 300 μm,425 μm,500 μm, 1 mm, 2 mm, 4 mm, 5.6 mm were used. Dry sieving of OBM and sand samples was done. Then after calculating the per cent retained on each sieve by dividing the weight retained on each sieve by the original sample mass, percent finer were determined The particle size distribution curves for sand and crushed overburden sample was plotted on semi log scale where sieve sizes (particle sizes) on horizontal logarithmic scale relating per cent finer on vertical arithmetic scale as shown in Fig.1.

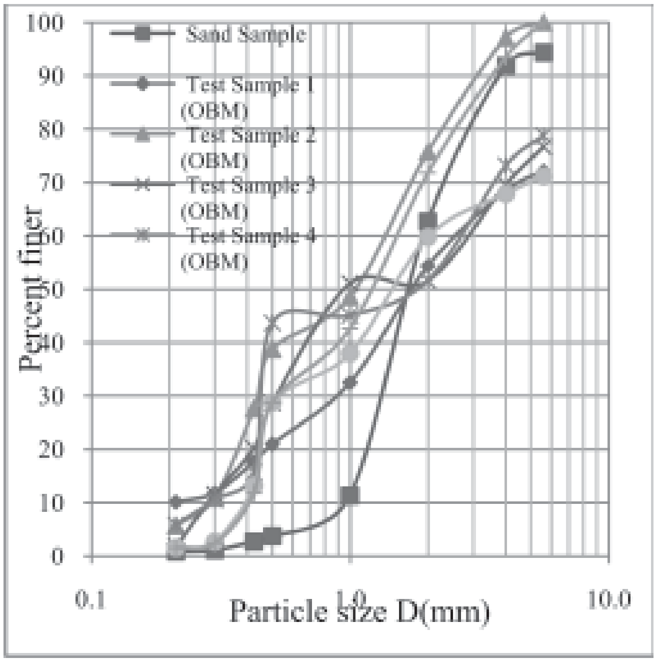


Fig.1 Particle size distribution used in the present study

The grain size distribution also shows following results:

Sand sample: gravel-7.46 %, sand-91.90%, fine-0.64%

OBM sample: gravel-3.15 %, sand-79.16%, fine-17.25%

Coefficient of uniformity (CU) and coefficient of curvature (CC) for sand sample and OBM samples have been computed and compared based on the particle size analysis as tabulated in Table 1. For OBM samples higher value of Cu (>4) indicates wider assortment of particle and well graded compared with sand sample.

Additional significant physical properties

Some additional physical properties were determined in geotechnical laboratory for both sand and OBM samples. These properties may form the basis for assessment of suitability of a stowing material in comparison with sand. The results are tabulated in Table 2.

TABLE 1: COEFFICIENTS OF UNIFORMITY AND OF CURVATURE OF PSD TEST FOR SAND SAMPLE AND OBM SAMPLES USED IN THIS STUDY

Test sample	C_U	C_C
Sand sample	2.00	1.09
OBM sample 1	12.74	1.43
OBM sample 2	4.83	0.46
OBM sample 3	9.66	0.32
OBM sample 4	8.97	0.27
OBM sample 5	5.00	0.35
OBM sample 6	4.02	0.40

TABLE 2: IMPORTANT PHYSICAL PROPERTIES OF STOWING MATERIALS.

Property	Sand sample	OBM sample
Dry unit weight γ_d (gm/cc)	1.93	2.00
Bulk unit weight γ_b (g/cc)	1.98	2.20
Specific gravity of solids, s	2.63	2.62
Relative density (gm/cc)	1.63	1.70
Void ratio at OMC	0.52	0.35
Porosity (%)	34.0	25.6
Bulking (at corresponding wc)	22.5	19.0
Percentage of air voids	34.1	25.6
Permeability (cm/sec) (Constant head method)	6.233×10^{-5}	1.037×10^{-6}
Shape of the Grains (visual)	Rounded	Rounded

Among the physical properties tabulated in Table 2, there is no significant variation for the properties like dry unit weight, bulk unit weight, specific gravity and relative density, shape of grains for OBM sample comparing sand sample. Void ratio, porosity and percentage of air voids of sand sample are more than that of OBM which consequently increase the bulking phenomenon in sand.

Permeability is necessary to ensure that excessive water needed to transport slurry into stopes from the surface, drains rapidly to allow for better placement and curing rates. Here permeability of both samples was determined by constant head method.

Experimental design and program

The experimental set up was developed in VNIT Nagpur. The perspective view of the experimental set up used in the present study is shown in Fig. 2. It consists of a pipe loop of total length 23.20 meter and internal diameter 37.5 mm, laid horizontally with several bends. The slurry mixture was prepared for a desired volumetric concentration in consolidation tank fabricated from mild steel with dimensions 2100 mm, width 2100 mm and height 1200 mm (capacity 5292 litre). The stirring arrangement was used for uniform mixing. This efflux slurry was then circulated using centrifugal self priming and agitating slurry pump (7.50 kW). This slurry was collected in the stowing tank fabricated from mild steel with dimensions having length 2100 mm, width 2100 mm and height 1200 mm (capacity 5292 litre) for deposition and settlement analysis. HDPE (High Density Polyethylene) pipes were used. Drive panel connected electronically with slurry pump was used to regulate the flow on the downstream side of the slurry pump.

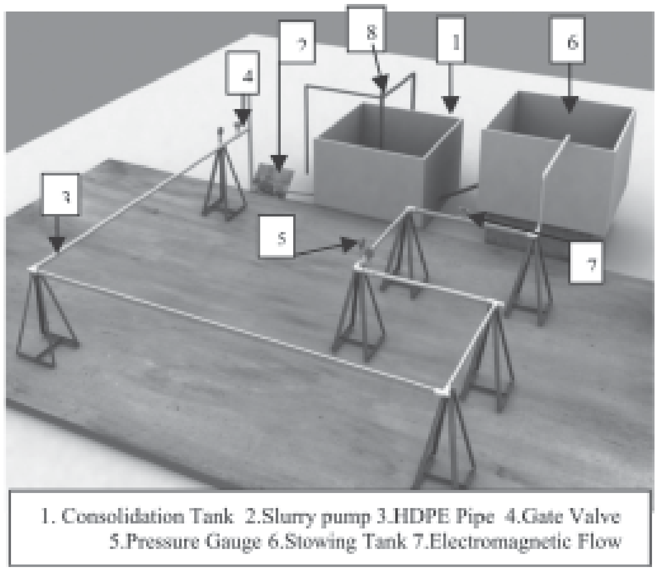


Fig.2 Perspective view of experimental set-up used in the present study

Experimental procedure, measurements and unit conversion

The experimental flow characteristics like flow rate (Outlet discharge) and pressure at requisite positions are directly recorded in the computer with data acquisition system using electromagnetic flow meter and pressure transmitters. The pressure drop loop was considered from PT1 (Pressure transmitter near the gate valve on suction side of pump) to PT6 (Pressure transmitter fixed after electromagnetic flow meter).

Pure water was initially circulated in a pipe loop for a wide range of flow velocities (1 m/s - 10 m/s). A complete record data of flow characteristics (flow rates, pressure etc) was recorded and saved in correspondent files. The same procedure was adopted for sand mixture and OBM mixture slurries for concentrations 0.04 C_v (concentration by volume), 0.1 C_v and 0.3 C_v. The data acquired from electromagnetic flow meter refers to the flow rates at those particular instances. The concentration of slurry was maintained and monitored.

Velocity through circular pipe for desired flow is computed by a formula from these flow rates as follows:

$$V = \frac{Q}{A} \quad \text{... (1)}$$

where,

Q = discharge through conduit (m^3/sec)

A = area of c/s of circular pipe (Ø=37.5 mm); (m^2)

Pressure gradient (pressure loss) for a test loop between PT1 and PT6 has been computed; taking the difference of pressures at point 1 and point 6 in kg/cm^2, then it was converted in to a unit 'meter of water' by multiplying with 9.9965 as 1 kg/cm^2 = 9.9965 m of water. The pressure gradient per meter length was converted in a unit of 'Pascal per meter' for a loop length =14.9 m. (Here 1 kg/cm^2 was converted in to 'Pascal' as 1 kg/cm^2 = 9.81 x 10000 Pascal.

Experimental results

Pressure gradient per meter length (i, kpa/m) for sand and OBM slurries having concentrations 0.04 C_v, 0.10C_v and 0.30 C_v have been calculated and plotted against increasing pipe flow velocities as shown in Fig.3. It has been observed for case (a) and case (b) of Fig.3 that as the volumetric concentration (C_v) increases the pressure gradient (i) also increases in relation with pipe flow velocity and the rate of change of pressure gradient for sand and OBM slurry shows steeper pattern when compared with pure water flow. As shown in case (c), for 0.04 C_v pressure gradient of OBM slurry have higher values compared to sand slurry transportation, but as concentration increased, for higher velocities pressure gradient of OBM slurry showed decreased values as described in case (d) and case (e) of Fig.3.

The linear equations (2) and (3) can be established for OBM and sand slurry transportation through circular pipe of internal diameter 37.5 mm as follows.

For OBM slurry:

$$i_o = 1.25 + 0.024C_{vo} + 0.35V_o \left(R^2 = 0.98\right) \quad \ldots \quad (2)$$

where,

i_o – pressure gradient for OBM slurry, (kpa/m)

C_{vo} – volumetric concentration of OBM, (%)

V_o – velocity of OBM slurry, (m/sec)

For sand slurry:

$$i_s = 0.49 + 0.03C_{vs} + 0.42V_o \left(R^2 = 0.95\right) \quad \ldots \quad (3)$$

where,

i_s – Pressure gradient for sand slurry, (kpa/m)

C_{vs} – Volumetric concentration of sand, (%)

V_s – Velocity of sand slurry, (m/sec)

Predicted pressure gradients for OBM slurry and sand slurry have been calculated using equations (2) and (3) respectively and compared to the experimental values as graphically presented in Fig.4(a) and Fig.4(b) for increasing flow velocities and volumetric concentrations 0.04 C_v, 0.10 C_v and 0.30 C_v. The regression statistics for both slurries show that percentage error between experimental and predicted pressure gradients have the value below 5% which is within permissible limit.

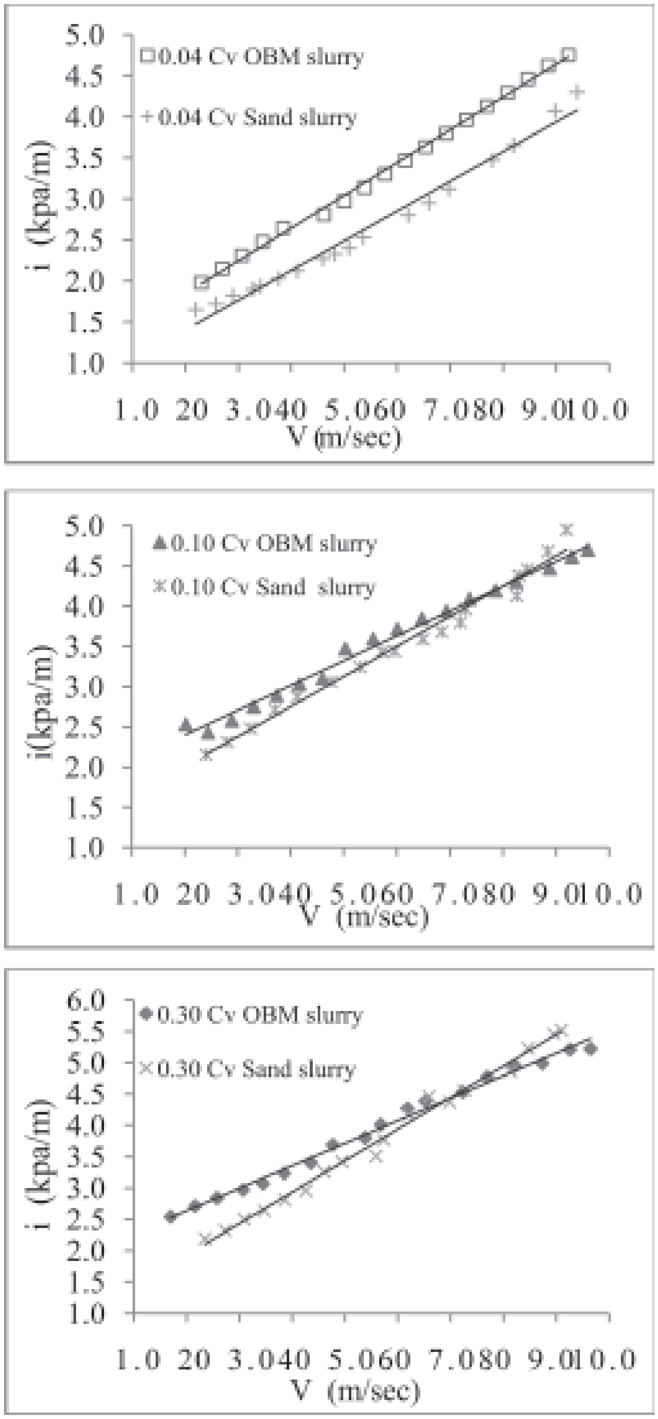
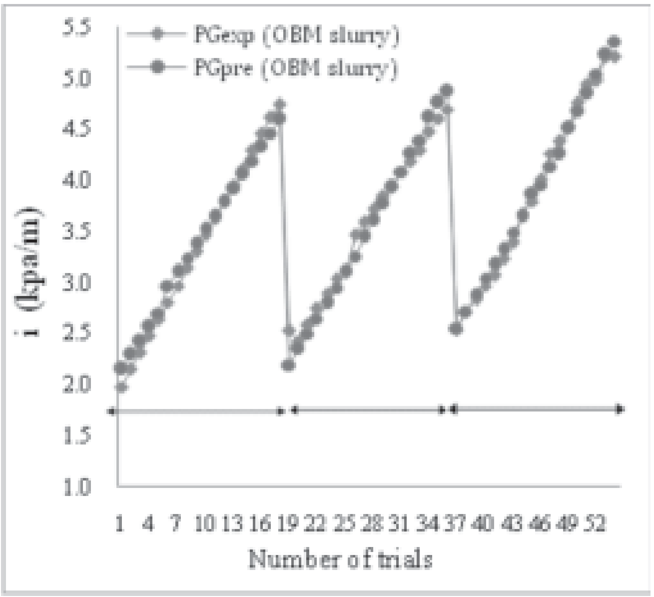


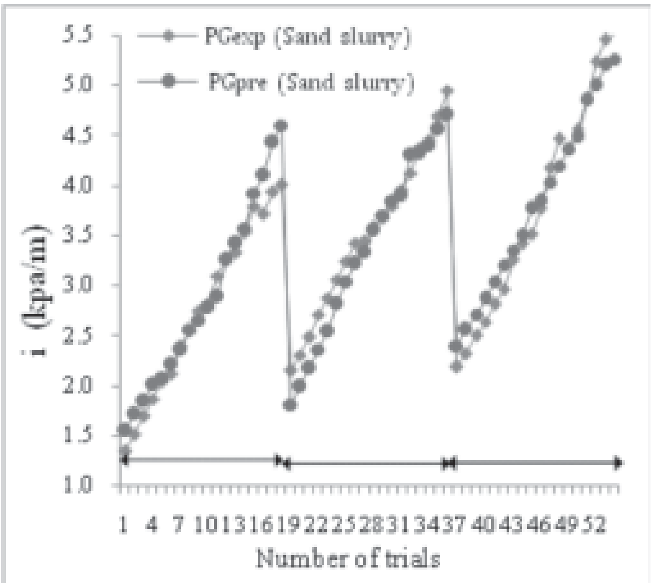
Fig.3 Variation of pressure gradients for 0.04 C_v, 0.10 C_v and 0.30 C_v

A relation described by Scott (1997) can be associated with these experimental findings to evaluate the per cent change in pressure gradient due to the carrier fluid. Thus the effectiveness of OBM mixture slurry concentration in comparison with sand mixture slurry concentration can be presented as:

$$\Delta i_{os} = \frac{i_o - i_s}{i_s} \times 100 \quad \ldots \quad (4)$$



(a) OBM Slurry



(a) Sand Slurry

Fig.4 Experimental and predicted pressure gradients

where,

Δi_{os} – Percentage change in pressure gradient for OBM carrier fluid related with pressure gradient of sand

i_o – Pressure gradient of OBM slurry, (kpa/m),

i_s – Pressure gradient of sand slurry, (kpa/m).

Fig.5 describes that percentage change in pressure gradient for OBM slurry in relation with sand mixture.

Water percolation characteristics

In underground mines, it is an important criterion to understand the settlement of solids in the voids after

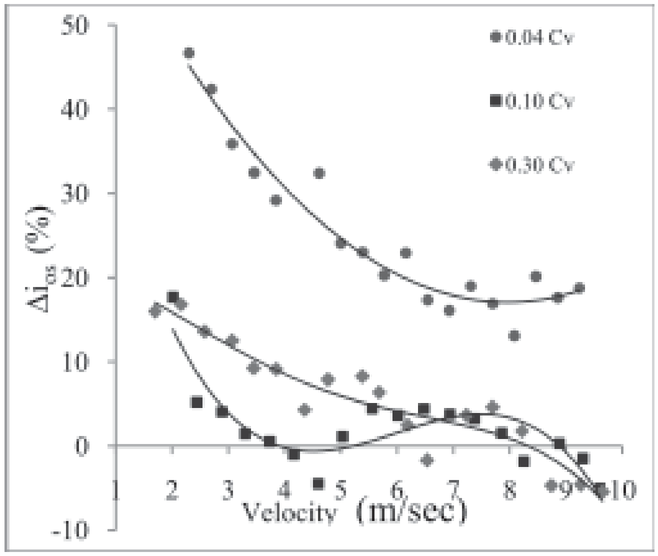


Fig.5 Percentage change in pressure gradients

placement of the slurry at deposition stage. Water gets percolated trough the barricades after placement of slurry in underground mines. The pack gets consolidated and does not remain in fluid state for a long time and prevent build of high hydrostatic heads at the barricades.

The settlement behaviour of solid particles of both sample were determined by preparing slurries with 0.25 C_v and 0.50 C_v. These slurries were poured in the buckets (capacity 20 litre) having equispaced holes (5mm) at the bottom for draining purpose. Then a weight of 5 kg was applied to measure the settlement in each bucket. After every two hour interval the settlement was noted down. Fig.6 shows the settlement behaviour of OBM sample and sand sample for volumetric concentrations 0.25 C_v and 0.50 C_v.

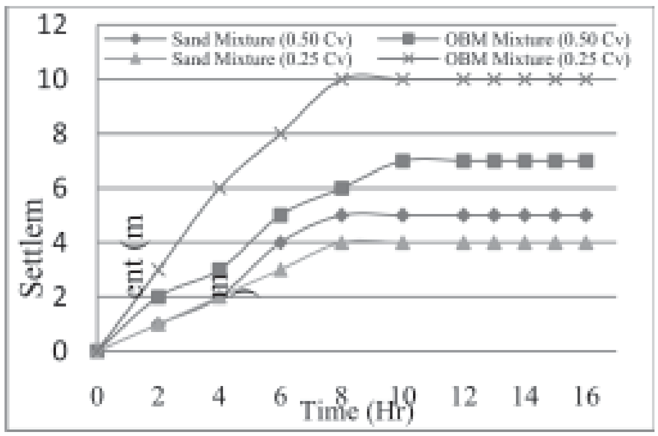


Fig. 6 Settlement behaviour in present study

Conclusions

Backfill is an important constituent of underground mining operations. The method of selection of backfill as a stowing material in place of sand has a wide range in terms of its physical properties and flow characteristics. On the basis of experimental investigation carried out in this paper some significant parameters concluded as follows.

(i) A backfill containing well graded particles (OBM sample) offer more resistance to pipe flow than one with uniformly graded particles (sand sample), all other factors being equal.

(ii) OBM sample contain large quantity of fine and clay particles in comparison with sand sample, these particles should be separated out or washed out before using for stowing purpose to avoid clogging. It was observed that these particles get accumulated to form a thickened paste with other particles, so at low flow rates reduces velocities causing pressure loss and ultimately reduction of power (energy loss) to pump the slurry to destination.

(iii) Most of the additional physical properties of OBM sample are comparable with sand as a stowing material.

(iv) Permeability of OBM sample is found to be lower than sand sample tested in this study as expected which is mainly affected by the fine particles, reduces percolation rate through voids. So these particles should be sorted out to ensure high percolation for draining criteria.

(v) Because of the presence of higher amount of sand particles in the OB samples, there will be fast removal of water passing through the OB material that is one of the characteristic features of stowing material.

(vi) It is observed from experimental analysis pressure gradient of OBM slurry for low concentration is higher compared to sand slurry. But as concentration increases, it is quite comparable for the range of higher velocities.

(vii) As shown in Fig.5, there is 15 %- 20 % reduction in pressure gradient occurs for higher velocities zone (6 m/sec to 10 m/sec) as the concentration increases from 0.04 C_v to 0.30 C_v compared to sand slurry. Negative values indicate a decreased pattern of pressure gradient (pressure loss).It refers minimum energy consumption to the system for OBM slurry, thus influences the chances of selection of OBM sample as a stowing material in place of sand.

(viii) Slurry residual settlement mainly affected by its water-draining and settlement characteristics which are closely related to each other. Faster settlement avoids clogging of the pores. It also eases drainage of the water.

Acknowledgements

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Notations and units

A – area of c/s of circular pipe, (m^2).

C_C – coefficient of curvature

C_U – coefficient of uniformity

C_v – volumetric concentration (%)

C_{vo} – volumetric concentration of OBM (%)

C_{vs} – volumetric concentration of Sand (%)

D – particle size diameter (mm)

Q – discharge through circular pipe (m^3/sec)

i – pressure gradient of slurry (kpa/m)

i_o – pressure gradient of OBM slurry (kpa/m)

i_s – pressure gradient of sand slurry (kpa/m)

PGexp – experimental pressure gradient (kpa/m)

PGpre – predicted pressure gradient (kpa/m)

V – average flow velocity (m/sec)

V_o – velocity of OBM slurry (m/sec)

V_s – velocity of sand slurry (m/sec)

γ_b – bulk unit weight (gm/cc)

γ_d – dry unit weight (gm/cc)

s - specific gravity of solids

Δi_{os} - percentage change in pressure gradient for OBM carrier fluid related with pressure gradient of sand.

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flow rate in fan on pressure fields and velocity fields in laneways were explored. The result showed that the effect of adjusting single factor (the local wind resistance, the wind pressure in fan or the air flow rate in fan) was rather limited to the wind pressure fields and wind speed fields in laneways, failing to reach the target of pressurization.

(3) In the orthogonal experiment, the wind pressure in pressurized area could reach the target value by using the combination process of the local resistance, the wind pressure in fan and the air flow rate in fan. The significant difference of the local resistance, the wind pressure in fan and the air flow rate in fan on the average air pressure, the air flow rate and the wind speed in laneways were found out. Based on the regression analysis, the parameters prediction equations of high altitude mines local pressurized ventilation were also obtained.

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