CEMENTED ROCKFILL IN MINING - A REVIEW

TECHNICAL REPORT NO. 38

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COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANIZATION, AUSTRALIA
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KEYWORDS:

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ABSTRACT:

This review examines previous applications of cemented rockfill in mining, and discusses the engineering role of this material and its potential for further development.

A number of factors suggesting the use of cemented rockfill in preference to hydraulic fill are given. The use of rockfill in structural mine control, the placement techniques and the methods of predicting performance are very much in the developmental stage. There is considerable scope for economic and structural optimization of rockfilling systems. The continued application of cemented rockfill to new and more efficient mining methods appears inevitable.

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1. INTRODUCTION

Uncemented hydraulic fill has been used in mines for over a century and in the 1940's became standard practice in many mines throughout the world. Prompted by the realization that fill should be considered as an integral part of the mining method, with a number of specific structural roles, significant developments have taken place in the search for suitable materials and in the determination of fill response. Hence, since the 1960's the introduction of cohesive strength through the addition of a cementing agent has become popular.

The functions of mine fill may be divided into two groups:-

Non-structural
(a) act as a working platform,
(b) provide for disposal of waste products,

Structural
(c) minimize ore dilution from caving,
(d) laterally support rock pillars,
(e) structurally support stope backs,
(f) permit maximum ore recovery (through mining of secondary pillars).
(g) provide access through the fill.

The structural role of fill (i.e. as an artificially introduced support system) is emphasised in the general trend in overall mine design philosophy towards having mine layout designed for the efficient extraction of pillars rather than stoping design being oriented towards maximizing production from primary stopes (Hull and Miller, 1974). In many pillar extraction schemes, fill plays a dominant structural role. Total ore extraction schemes require that fill pillars should be able to stand a considerable height without lateral support and also remain stable during the choked drawing of adjacent ore.

In structural applications, the most advanced and widely studied material is hydraulically placed cemented fill composed of mill tailings and a cementing agent and usually combined with sand or small scale aggregates. Mining with cemented hydraulic fill is costly and there has been a continuing search for a cheaper alternative high strength material. Apart from cost, there are other disadvantages of cemented hydraulic fill such as the problems of controlling mine water, availability of materials and methods of distribution underground. Consequently, mine planners were led to trials of cemented rockfill. Judging from its limited application, some advantages of this material are;
(a) the high strengths obtainable especially when used as a weak concrete,
(b) suitability to large scale operations and high filling capacity,
(c) relatively low cost per unit volume filled.

2. EXISTING APPLICATIONS AND TECHNIQUES

To the writers knowledge, cemented rockfill has been used at only three mines, two in Canada and one in Australia.

At Kidd Creek Mine, Timmins, Ontario, cemented rockfill is used to mine secondary pillars in 130 m (400 ft) lifts using a choked draw. Hull and Miller's (1974) report contains the following limited information on fill operations at Kidd Creek Mine. The rock is mined from an open pit and crushed and well graded from -150 mm down. The material is dropped down raises to silos and a central concrete batching plant where lean concrete is produced. The prepared concrete mix is taken by scoop trams to the individual levels and tipped into the stope at selected points in the pillar walls. Strengths (uniaxial compression) of the order of 7 MPa (1000 psi) for cemented graded rock are achieved with an overall cement content of 5.4%. The choice of materials as well as the method of placement reflect the new concept of considering the fill as a weak or lean structural concrete rather than as a reinforced or stabilized fill.

A cemented rockfill is also being used at Noranda's Geco Mine in north western Ontario. Here, wast rockfill broken to 100% plus 300 mm is dumped from the surface down passes to fall directly into stopes. Considerable particle degradation occurs in the fill passes and a major segregation of particle sizes occurs in the deposit. Cemented hydraulic sand fill (3.3% Portland cement) is allowed to percolate through the mass of quarried rock to cement at least the sides of the pillar. After 6 months to 1 year has elapsed after the completion of filling, the adjacent stope or pillar is blasted and removed by choked draw. Though the approximate strength is of the order of only 0.7 MPa (100 psi), stopes up to 150 m (500 ft) high and up to 30 m (100 ft) wide have been successfully pulled. Recovery is stated at 100% with 10% dilution. In the opinion of Hull and Miller (1974), heights up to 2½ to 3 times that which will stand unsupported may be extracted using a choked draw.

At Mount Isa Mine, cemented rockfill is presently being used to fill primary stopes in the 1100 orebody. (Barrett, 1973). Crushed rock particles up to 300 mm in diameter are distributed to various levels via fill passes and then transported by a horizontal conveyor system to individual stopes. Cemented hydraulic fill containing approximately 6% equivalent Portland cement content is dropped simultaneously into the stope in the ratio, two parts rock, one part hydraulic fill. The unconfined laboratory compressive strength is of the order of 1.0 MPa (150 psi). It is intended that in future mining alongside these pillars, stope heights up to 250 m (800 ft) will be extracted using a choked draw.
3. FACTORS AFFECTING TYPE OF FILL USED

A comparison of these three mining applications with the widespread use of cemented hydraulic fill indicates that where fill serves as a major structural facility, the cement content is higher than for non-structural applications. Non-structural hydraulic fills commonly use 3% cement content. In general, higher fill strengths permit higher backs with open stoping and require a low degree of sophistication for tolerable draw control.

A further comparison establishes that while cement proportions are not very different, compressive strength is. Three different placement methods have been described and it appears that where hydraulic placement (either simultaneous with or subsequent to the rockfill) occurs, strengths are relatively low. In Portland cement-granular systems, higher strengths are obtained with mixes having lower water cement ratios if this is consistent with the practical attainment of high density. It appears therefore that better strength and deformation properties may be achieved with mechanically placed cemented fills than with hydraulically placed fills as a result of the lower water:cement ratios present. The use of large rock particles in mine fill offers further advantages:

1. The volume and density of the fill may be increased considerably without a reduction in strength when compared with hydraulic fill containing the same quantity of cement.

2. Because of the lower specific surface of the large rock particles, both the cement content and the water cement ratio may be reduced drastically with no detrimental effect.

A number of promising materials are being developed for large scale applications (e.g. dams and mine fill). These materials require low water cement ratios in contrast to the high ratios needed for hydraulic placement. At the University of California, Berkely, J.M. Raphael is developing a low cement sand mixture in which strengths of up to 10 MPa (1500 psi) in uniaxial compression may be obtained using only 5% Portland cement (Worotnicki, pers. comm., 1975). To achieve this, a very low water content is used and the material is compacted by impact.

Under the direction of G. Zahary, the Canadian Mines Branch at Elliott Lake is developing a no-fines aggregate mix for use as mine fill. (Worotnicki, pers. comm. 1975). Again, water content is kept to a minimum by reducing the wetted surface. Strengths of the order of 4 MPa (600 p.s.i.) have been obtained through the use of a low cement mortar and uniform aggregate in the 20 - 25 mm range.

The principal differences between cemented rockfill and other cemented fills are the very large particle sizes and the attendant restrictions on the methods of placement possible. Consequently, there has been some reluctance to use cemented rockfill due to the higher handling costs (especially in small scale operations) and the difficulties in assessing mechanical properties. The following considerations however, suggest that in future, the use of cemented rockfill may be more widespread.
1. Information from a recent survey by the Fill Sub-Committee of the Canadian Advisory Committee on Rock Mechanics indicates that the economic availability of fill material takes precedence over the optimization of fill performance. The most common material in use is hydraulic fill prepared from mill tailings, but in future, tailings stockpiles will be depleted. In these circumstances, other bulking materials would become more favourable, notably quarried rock.

2. Through the use of large aggregate particle sizes, the total proportion of cement required (the most expensive item) for a given fill strength will be reduced. This aspect assumes greater importance when fill is required to perform structural functions and fill strength and cement contents approach that of weak concrete.

3. As better strength and deformation properties are required for structural applications, placement methods which maintain a low water content ratio will become more favourable. This will mean that mechanically placed cemented rockfill with lower water cement and cement aggregate ratios than hydraulic fill will be more economic.

4. To date, the uncertainties in assessing in situ rockfill properties and in analysing cemented rockfill behaviour may have acted as a deterrent to its use. This situation is expected to be alleviated with the development of rockfill technology. The economics of placing rockfill do not appear to be too disadvantageous in relation to the corresponding costs for hydraulic fill. At Zinkgruvan mine in Sweden, waste rock and gravel is mechanically placed by truck at the same order of cost as for hydraulic fill though the filling capacity is somewhat less. The same equipment is used for filling as for ore mucking (Mattson, 1973). A similar technique of filling with dry rock is used at Kamoto mine, Zaire, to fill stopes which initially require little direct fill support.

By recognising the structural role of mine fill the opportunity for manipulating the properties of the material beyond the practice of using the fill to occupy voids as is often done with hydraulic fill is possible. Examples of this approach are:

1. Lining the primary stope (before or during filling) with a membrane or tensile reinforcing material to improve structural integrity or resistance to abrasion.

2. Cementing particular zones more strongly such as the outer shell or lower area of the fill pillar.

4. ASSESSMENT OF STABILITY

The proper use of both hydraulic and rock fill as a mine support system has necessitated the development of techniques for assessing the stability and engineering performance of the fill. To this end, considerable theoretical work has been done, almost exclusively with cemented and uncemented hydraulic fills using finite element techniques.
The results of Pariseau et al (1973), Hoffner (1973) and Kvapil and Blake (1973) have demonstrated that hydraulic fill may have a significant stabilizing effect on stope wall closure and pillar stresses. The writer is not aware of any reports of similar analyses to determine primary pillar stability for practical applications of cemented rockfill.

The problem of assessing fill pillar stability using stress distribution methods is complicated by a number of factors not significant in hydraulic fill.

1. Material properties are very difficult to determine because of the large specimen volume required for representative measurement, and the inability to core and test the material in the laboratory.

   Extensive investigation of material properties has been carried out by Gonano et al (1977) using a specially designed large scale triaxial cell.

2. Size effects are present due to large scale inhomogeneity in properties, brittle fracture behaviour and structural features of the material (Brown and Gonano, 1975). The similarity with rock masses in this respect is evident and as such, no rationale for determining in situ strength and modulus is available. One novel approach is given by Gonano and Kirkby (1976).

3. The structural features of the pillar formed during deposition are a complex function of material grading, stope geometry and emplacement method and are difficult to determine.

   Two separate approaches for the representation of fill structure and variability may be used. The first is to develop methods for predicting the distribution and nature of the material from a knowledge of fill proportions, stope geometry etc., and then represent these features explicitly in a numerical stress distribution model. The other is to assume an equitable distribution of all components entering the stope and hence assume uniformity of mechanical response properties in the stress distribution model. Analyses to determine the effect of large scale inhomogeneity from deposition on pillar stability are at present being conducted.

Once the problems have been overcome, analysis techniques which allow for elastic-plastic, anisotropic and ceep properties may be applied, Programs which incorporate these practically realistic features (e.g. Aghabian, A-Solid, Sap, Non-Sap) are commercially available. Although these programmes provide for 3- D analysis, no attempt to use 3- D appears justifiable considering the reliability of the input data.

5. CONCLUSIONS

1. In the attainment of high strength fills (uniaxial compressive strength 3.5 - 7 MPa), hydraulically placed fills are not particularly suitable, because of the practical requirement of high water cement ratios. It is apparent that in many applications the structural functions of fill are more economically fulfilled using mechanical placement.
addition to the advantage of low water cement ratios, mechanically placed fill may contain large rock particles at no extra inconvenience but with the attendant advantages of bulking, reduced cement content and better frictional and attrition characteristics.

2. Judging from other mining experiences, considerable potential exists for improving material properties significantly beyond that presently achieved at Mount Isa and Geco mines if this is proven necessary, without increases in cement content. Non-hydraulic methods of introducing cement into the stope would improve both the structural and strength aspects of the fill pillar.

3. Though still in the developmental stage, the introduction of cemented rockfill as an integral part of certain mining methods, with its attendant economics will almost certainly lead to more efficient mining and improvements in the percentage of ore recoverable.

6. ACKNOWLEDGEMENTS

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7. REFERENCES


