

CEMPAKS : STOPE AND GULLY SUPPORTS

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Abstract

The paper describes an R& D programme carried out on Cempak, a proposed stope support system for deep, tabular, hard rock gold and platinum mines; which looks in particular into the issue of convergence after attainment of peak load. Cempak fundamentally comprises square or rectangular, low-strength grout packs, reinforced internally by sheets of successive, horizontal, parallel layers of ductile steel welded mesh. Laboratory and underground trials have checked and confirmed the design method and Cempak's load-bearing and yielding properties. Grout pack systems have lost popularity in the South African gold-mining industry, and Cempak has failed to capture any share of this shrinking market. An opportunity has however arisen at certain of the larger and deeper platinum mines. Cempak has been asked by the Lonmin Group to participate in a comprehensive programme where Cempak's claimed properties will again be checked and tested in the laboratory as well as underground.

Introduction

A new construction material, Reinforced Earth (RE), was invented in France in the 1960s by a French engineer, Henri Vidal, who based the technique on formation of a composite material through the association of compacted frictional fill and linear soil reinforcement. RE is now used world wide in a variety of civil engineering structures, but generally under the name MSE (mechanically stabilised earth), in view of a number of competitive systems having arisen since the grant of Vidal's original patents.

In South Africa, Reinforced Earth (Pty) Ltd (RESA) was formed in order to promote use of the material in this country and in African territories generally. Notwithstanding its principal activities in civil engineering however, the company also detected possible applications for the Reinforced Earth principle in underground mining activities – essentially as support units in deep, hard rock mines. For several years therefore an associated company (REMS) has pursued an R&D programme devoted to developing support systems of various types – grout packs, precast concrete packs and gully packs in backfill stopes.

Formal results of the R&D programme have been recorded in three separate documents; termed for convenience in this paper as the Wits report (1988)¹, the COMRO report (1992)² and the Miningtek report (2002)³. The paper will however describe and discuss only the Cempak, a reinforced grout pack for stope support and possible gully support in certain cases.

Comment on theory and design of Cempak will essentially be based on the three reference documents cited above, together with experience gained in non-reported underground and laboratory trials. For easy reference, statements deriving from the reports will either be summarized or quoted verbatim.

Description and purpose of Cempaks (Wits Report)

The Wits Report was devoted essentially to Cempaks, and established basic theory and design procedures that in fact were found also to apply to support systems that developed later in the programme.

Cempak was originally designed for gold mines as a local support that would exhibit initial stiffness until reaching yield point, yield at constant load until reaching compression of 25-30% (thereby eliminating sudden drops in load after attaining peak load), and then accept increased load by virtue of “squatness”. Desired theoretical performance is shown in Figure 1.

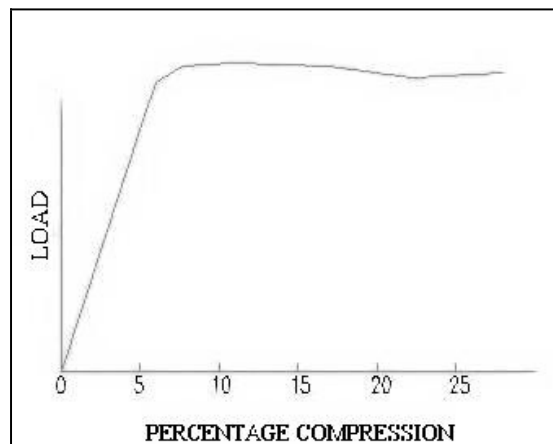


Figure 1. Ideal Load-Compression characteristics

Cempak's essential materials originally comprised:

- geotextile permeable bag (polypropylene or polyethylene)
- cemented grout, contained in the bag or bags.
- reinforcement, preferably sheets of annealed welded mesh placed in horizontal array at constant vertical spacing, within a single bag.

Cempaks were originally designed to have the mesh reinforcement fixed into position in square bags of height equal to stope width. (Figure 2). This pattern however produced a heavy bag and concomitant problems in handling and installation. An improved, more

user-friendly pattern was later devised and adopted, and is described in this paper under the heading “Underground Trials”.

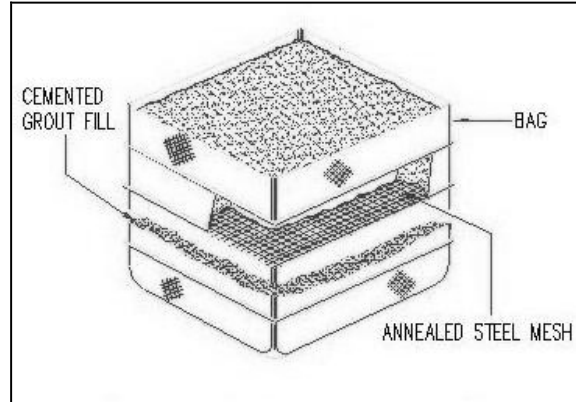


Figure 2. Diagrammatic view of pack assembly variables affecting performance

Reinforcement In order to produce desired yielding properties, ductile welded steel mesh was selected as the most suitable reinforcing medium. High tensile commercial mesh of the order of 50x50x4 mm diameter was most commonly used, after having been annealed to a ductility of about 25%. Low-carbon steel was preferred to “fencing” steel in order to obtain the required ductility more easily.

Fig. 3 compares performance of two 1-metre square reinforced packs, reinforced respectively with high-tensile and ductile mesh. The pack reinforced with ductile mesh exhibits superior properties after yield, although peak loads are similar.

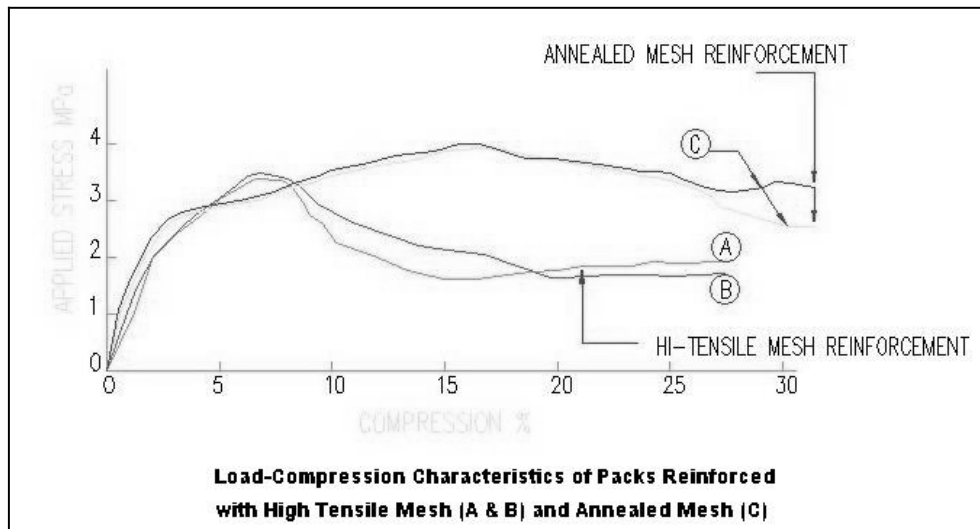


Figure 3. Load-Compression characteristics of packs reinforced with high tensile mesh (A & B) and annealed mesh (C)

Height-to-width ratio (h/w): “Strength and yielding properties of most mining supports improve with increased ‘squatness’”(Wits Report). The tests showed that increasing slenderness resulted in reduction of yield and ultimate stresses, but did not adversely affect the post-failure yield pattern. Nevertheless, h/w ratios greater than 1,5 are generally not advisable.

Cementitious binders and extenders: Most types of binders and extenders were found suitable; opc, rhc, slagment, flyash, accelerators, plasticisers. Choice depends largely on strength requirements, pumpability, costs and special circumstances at each mine. Relative densities of pumped grout ranged from about 1,7 at gold mines to 1,9 at platinum mines.

Cempak requires a low grout strength, which should not exceed a maximum of 2-3 MPa when load is first applied. In fact, in terms of MSE theory no cementitious binder is required at all, unless high initial stiffness is a desired criterion. Cements and cementitious binders facilitate pumping however, and eventual hardening of the grout helps to prevent spillage and loss of material during the blast.

Backfill material: Various types of backfill material were tested: gold mine tailings (classified and unclassified), platinum mine tailings and natural sands Mix designs were therefore obliged to cater for differing properties of available aggregates, and relative pumping densities depended on the nature of the parent rock. Choice of backfill aggregate obviously depended on local availability and cost.

Strength and pumping performance both improve with increased coarseness of aggregate, and gold mining tailings required cycloning in order to remove their finer fractions. (In terms of MSE theory the coarser the backfill, the better the performance. Spherical rocks in contact with the reinforcement would comprise an ideal backfill that would bring about immediate strength and stiffness without the need for cementation).

Design

The Wits Report sets down: “In attempting to produce a pack with given characteristics, no single parameter can be treated in isolation. A balance of the effects of the various parameters therefore has to be struck in order to produce the performance required for each circumstance. This is the essence of the design method that has been evolved”.

In theory, compaction of the backfill material to a high density would probably achieve desired initial stiffness and obviate the need for cementation, but confined space in both narrow and wide stopes would clearly preclude the use of conventional and economic compaction equipment. Cementation at low strength therefore becomes an obvious alternative. In the early stages of compression the pack therefore behaves in the manner of reinforced concrete, but when the cemented grout starts to fail the MSE action of the reinforced backfill takes over the imposed loads.

“Too high a grout strength would in any event result in cracking of the stronger grout under load, because the reinforcement would be strained over only a short length. Consequent failure of the reinforcement would result in sudden drops in load. Design of packs therefore requires a balance between grout strength and steel content per unit volume to acquire the required stress-strain behaviour” (Wits Report).

Mass of steel per unit volume was calculated using the Rankine formula and conventional MSE design theory.

The tests also showed that it was possible to design a stiff indestructible pack (possibly required by some mines) by providing sufficient reinforcement to prevent yield at working loads.

COMRO Programme

The Wits Report had been presented to a conference on backfill, held under the auspices of the Association of Mine Managers, and resulted in an invitation from COMRO for REMS to participate in a collaborative programme that had the objective of taking the Cempak concept a step further.

The COMRO programme in fact proved to be most fruitful, and besides checking on Cempak it produced two further possible support systems. COMRO's contribution to the Cempak concept however lay primarily in checking findings of the Wits Report by carrying out a new series of tests, but on larger-size packs. (The Wits programme had been carried out on mini-packs).

COMRO's report confirmed the Wits Report's theory and conclusions, and COMRO recommended that the next step should comprise underground trials to check installation procedures and practical performance.

Underground Trials

Underground trials took place in mines where surface plants were already in place for pumping of conventional grout packs.

Unisel Gold Mine

About 10-12 grout packs were installed, using the single bag system. (Figure 4) Grout strength was about 8 MPa. A few extra packs were filled with a quick-setting cementitious powder known as Hydropack, which reached about 2 MPa almost instantaneously with the addition of water only.

All the packs performed satisfactorily, despite the high grout strength, and also proved capable of withstanding blast close to the face. Nevertheless, mine management foresaw handling and installation difficulties plus the possibility of plant breakdowns, all of which

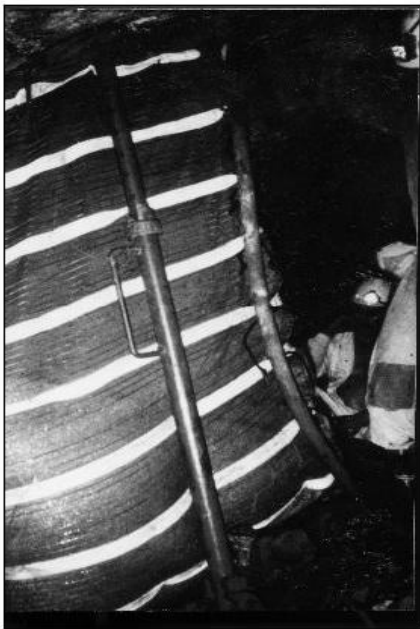
dissuaded them from switching their support system to Cempak. In any event, after a change of ownership the mining system at Unisel was radically altered and the use of all types of grout packs was either abandoned or suspended.

Unisel's management happened to be correct in realising that the single-bag form of assembly raised difficulties in underground transport, handling and installation, especially in their wide, steep stopes. A modular form was then devised, and is described in the COMRO report, page 3.

“The pack is built up using a number of ‘pillows’, i.e. permeable textile bags of low height-to-width ratio which contain the pumped grout. These are separated from each other by single layers of weld-mesh until the requisite height is reached. Each layer of mesh is connected to the next using high tensile steel clips to ensure correct spacing, prevent bulging of the bags and improve the stability of the pack. The adoption of a modular system also eliminates the need to manufacture bags to predetermined heights.”

One could also add to the above that support requirements, in the form of propping and shuttering, are reduced and simplified”

Figure 5 depicts a full-size modular or “pillow” Cempak under test at CSIR Cottesloe.



**Figure 4. Square Cempak
(at Unisel Gold Mine)**



**Figure 5. Modular Cempak
(in test at CSIR)**

Joel Gold Mine

About 30 “pillow” Cempaks were installed in a mechanised mining stope at Joel Mine, and again the mine authorities appeared to have been satisfied with performance. Moreover, the grouting contractor’s team found little difficulty in installing the pack assemblies, after training and instruction from the suppliers. (Figure 6 - – COMRO annual report 1990 – Unisel Gold Mine)

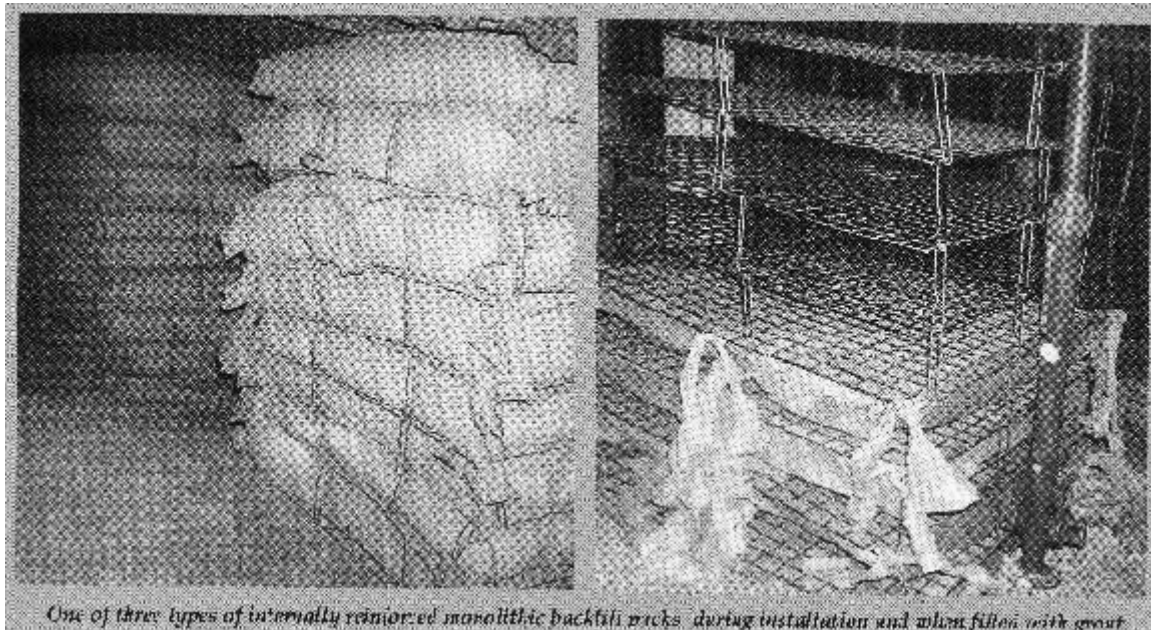


Figure 6. Modular Cempak (at Joel Gold Mine). Extract from COMRO Annual Report 1990

A change of ownership and a decision to abandon mechanical mining brought about changes in support systems at the mine, and the use of all grout pack systems was abandoned.

Great Nologwa Gold Mine

A circular pack form was adopted in monitored trials at Great Nologwa mine during the 2001-2002 SPII programme (Miningtek Report), using a single bag to contain the steel, in an attempt to comply with the pack-in-the-pipe system then in favour at the mine. (Figure 7)

These packs showed no advantages however over square packs; either in performance or cost.

New Programme at Platinum Mines

At the time of writing it is apparent that, for whatever reason, South African gold mines seem to have abandoned the use of all types of grout pack systems. Hopes for commercial exploitation of Cempaks therefore rest for the present only in the platinum mines.

Platinum mines have been extensive users of grout packs for many years, but packs have not required long-term yielding characteristics, mining depths having been comparatively shallow. However, increased and increasing depth of platinum mining has recently changed the picture, and platinum producers foresee that yielding packs might be required in order to accommodate possible convergence, and possibly help solve other problems.

In fact, early in 2005 tests were conducted under Lonmin auspices in the CSIR Cottesloe laboratory on two full-size Cempaks, 1m x 1m x 1,2m high, using grout from the Karee Mine plant. Performance curves, which approximated closely to design expectations and appear to satisfy load and convergence requirements, are shown in Figure 8.

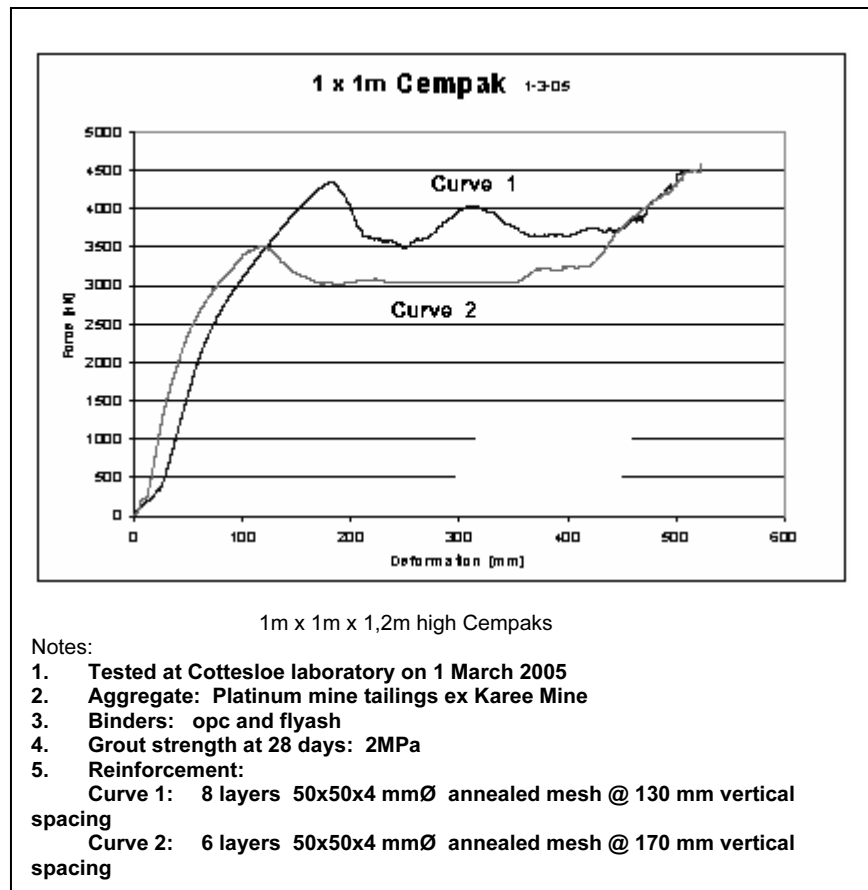


Figure 8

A Lonmin programme of laboratory and underground testing in the above regard has recently been initiated, and will also include investigations into mechanisation and pillar substitution. It is hoped that Cempak will be able to play a positive role in all aspects of the programme.

Comments and Conclusions

1. "A design method for Cempaks has been evolved which can, with a reasonable degree of accuracy, predict their load-carrying and post-failure performance." (Wits report).
Recent tests at CSIR Cottesloe laboratory tend to verify the above contention.
2. Cempaks exhibit advantages in mines requiring pack supports which are capable of producing both high strengths and yielding properties
3. Cempaks need not necessarily be square in plan. They lend themselves to a rectangular shape, which might be advantageous in certain cases; e.g. long-axis packs for pillar substitution or for gully support.
4. For any given set of underground conditions, a certain amount of preliminary trial and error would be required in order to balance the factors affecting performance: steel content, grout strength, h/w ratio, backfill material. Such trials could possibly be carried out initially on mini-packs. In this respect the Wits report sets down: "Although full-scale tests would be desirable and are recommended, the test programme has shown that reasonably accurate predictions could be made from mini-packs (300 mm square), and that scale effect is not significant".
5. Based on tests on standard Reinforced Earth structures in civil engineering applications, Cempaks would probably perform satisfactorily if subjected to seismic events.
The COMRO report in fact set down results of their dynamic tests on cemented and uncemented mini-packs: "The cemented pack appeared to behave in a brittle manner, shedding load during the rapid load phase then building it up in a similar fashion to the uncemented pack. This suggests that the rapid loading occurred before the pack had reached its yield load, failing the cement bonds and leaving the pack in a similar state to that of an uncemented one. The fact that the load still builds up after the rapid loading indicates that the steel did not fail completely".
6. During trials in the gold mines, main objections to the use of Cempaks included
 - (i) capital cost
 - (ii) running costs of grout plant systems
 - (iii) fear of plant breakdowns and consequent loss of production

The above objections have largely been overcome in the platinum mines, which have successfully been using sophisticated grout plants and pumping systems over a long period.

7. Specific cost advantages of Cempak:
 - (i) Saving in cementitious binder costs by virtue of low design strengths. At present costs of cementitious materials and aggregate at the platinum mines, for example, 2MPa grout would cost in the order of R90/ton less than 8 MPa grout..
 - (ii) the modular system of construction (“pillow” Cempak) avoids wastage of bag material and steel. Each pack is able to be built to the exact required width of stope.
 - (iii) “pillow” Cempaks reduce costs of shuttering and propping during installation.
 - (iv) design of Cempaks is based on recognised theory, requiring a lesser amount of subsequent testing by trial and error.
8. Ductile steel reinforcement is the favoured reinforcing material. Steel furthermore retains its properties of strength and modulus of elasticity at temperatures generated underground.

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