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SOIL REINFORCEMENT IN MINE BACKFILLING

RENFORCEMENT DU SOL DANS LE REMPLISSAGE DES GALERIES DE MINES

BODENVERSTÄRKUNG DURCH FÜLLEN VON HOHLRÄUMEN IM BERGBAU

In examining the applicability of reinforced earth principles in mine backfilling, various chemical agents and mechanical reinforcement have been assessed and the requirements of a reinforced sandfill system were identified. The desired reinforcing material not only has to possess substantial tensile strength and be non-corrosive, but also needs to improve the shear strength and compressive stiffness of the sandfill material. A chemical reinforcing agent such as cement appears to provide higher compressive strength than using mechanical reinforcement. From the strength performance of mechanical reinforced samples, it would seem that the mechanical reinforcement techniques may be applicable in shallow mining wherein a stepwise stope extraction method is employed.

Bei der Untersuchung der Verwendbarkeit der der Bodenverstärkungsmethode zugrundeliegenden Arbeitsregeln auf das Wiederfüllen von Bergbauhöhlungen wurden mehrere chemische Wirkstoffe abgeschätzt. Danach wurden die Anforderungen des Systems mit Verwendung des Verstärkungsmaterials bestimmt. Das gewünschte Verstärkungsmaterial braucht nicht nur eine beträchtliche Spannstärke zu besitzen, sondern es muss auch nichtkorrosiv sein und die Scherstärke und die Zusammendrückungskraft des Füllsandes erhöhen. Ein chemisches Verstärkungsmittel, wie Zement, scheint eine grössere Zusammendrückungskraft zu ermöglichen, als die, die durch mechanische Verstärkungsmittel zu erzielen ist. Nach der Leistungsfähigkeitsprüfung der mechanisch verstärkten Sandproben ist anzunehmen, dass sich die Technik des mechanischen Wiederfüllens beim nichttiefen Bergbau anwenden lässt, wobei eine treppenförmige Strossengewinnungsmethode benutzt wird.

1 INTRODUCTION

In mining with backfill, Portland cement is broadly used to alter the characteristics of backfill and increase its effectiveness. However, an exclusive use of cement not only leads to a high cost in the overall mining operation, but also has adverse effects on mill circuit control. In some mines a percentage of Portland cement has been replaced by other pozzolans, such as flyash or ground slag, in order to reduce the unit cost of backfill.

In some cemented sandfill, the agent acts to stabilize the fill mass by producing cohesive layers in an otherwise cement-lean mass. The role of these layers appears to be related to a reinforcing mechanism. Although the practice of using reinforced earth for appropriate geotechnical engineering projects is quite well established and has been demonstrated on many successful structures, the degree to which this technique is applicable to mine backfilling still remains unknown. Thus extensive studies both in the laboratory and in the field are required to evaluate this new conceptual application.

2 LABORATORY TESTING

2.1 Test Programme

The testing programme was designed to investigate the potential of using reinforcing techniques for improving the performance and strength of sandfill in mine backfilling. Standard drained triaxial tests were performed on 38 mm diameter samples of plain, cemented and reinforced sandfill in order to establish the strength parameters and deformation properties. Direct shear tests, with a 100 mm square shear box, were conducted in order to have a closer insight of the soil-reinforcement interaction.

2.2 Materials

The soil used was a uniform, medium to fine quartz sand. Pure quartz sand was employed in order to simplify the mineral composition of the mine fill model. Some of the physical properties of the sand model are:

Special gravity, G_s = 2.61
Minimum dry density, $\rho_{d,min}$ = 1.43 Mg/m^3
Maximum dry density, $\rho_{d,max}$ = 1.86 Mg/m^3
Coeffieient of uniformity, C_u = 2.93
Mean diameter, d_{50} = 0.18 mm

Various reinforcing materials have been employed for the investigation; these included Portland cement type A, woven polyester fibre, fibermesh (polypropylene), fibreglass and kaolin clay. The tensile strengths for woven polyester fibre and fibermesh are respectively 560 MPa and 550 MPa, and the Young's moduli of the geotextile materials are 4180 MPa and 3445 MPa respectively.

2.3 Sample Preparation

Test samples were prepared with a moisture content of 6 percent. Cemented samples were cured at 22°C for 7 to 28 days before testing. For reinforced sand specimens, 3 layers of reinforcement were normally introduced. Portland cement and 19 mm long fibermesh (0.1 g per sample) were used either in the form of layers or as a homogeneous mixture with sand. Whereas woven polyester fibre and fibreglass mat were only employed as reinforcing layers, 10 percent by weight of kaolin clay was uniformly mixed with 3 percent cement and sand. To alter the percentages of reinforcement, 6 percent and 3 percent by weight of cement were introduced to the samples.

3 STRENGTH AND DEFORMATION CHARACTERISTICS

Triaxial test results generally indicated an increase of shear strength, in terms of cohesion and internal friction angle, with the introduction of reinforcing elements. The effect was particularly pronounced for samples reinforced with cement. It is observed that the compressive strength of cemented samples depends significantly on the cement content and curing duration of the samples (see Figures 1 and 2). Samples with cement layers resulted in a lower strength compared with the uniformly cemented specimens. Addition of clay or layers of woven polyester fibre and 6 percent cement discs to 3 percent cemented samples induced further increase in compressive strength of the soil mixture (Figure 3). The presence of reinforcing layers also increased the failure strain of the samples (as shown in Figure 1). It was also noted that the results exhibited a trend to increasing compressive strength and strain at failure with increasing confining pressure.

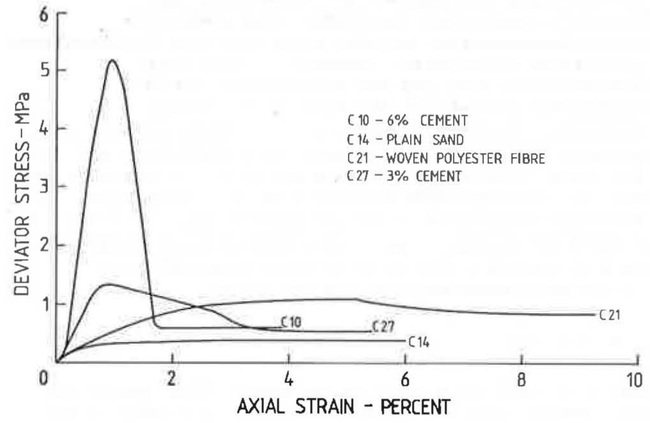


Figure 1 Stress-strain relationship of reinforced and unreinforced triaxial samples

Tests with fibermesh reinforcement showed that the failure mechanism is largely the result of a lack of adherence between the soil and the fibre. In fact the fibermesh fibres did not break during the tests. The reinforcing effect resulted in slightly increasing the internal friction angle with no evidence of an apparent cohesion. It is also noteworthy that the fibreglass material did not appear to impart significant tensile strength to the soil mass. This was due to the fact that the strands were held together by soluble resin binders and the material lost its strength whilst in contact with water.

Whereas unreinforced sand samples failed in a bulging manner, a formation of an inclined plane was obtained for cemented samples. With regard to samples with reinforcing layers, bulging of samples was observed between the reinforcing elements unless a shear band was introduced. The effect of introducing a celluloid former around an unreinforced sand sample increased the compressive strength from 0.48 MPa to 0.52 MPa. The fracture morphology of the reinforcements suggested that the reinforcing elements failed in tension.

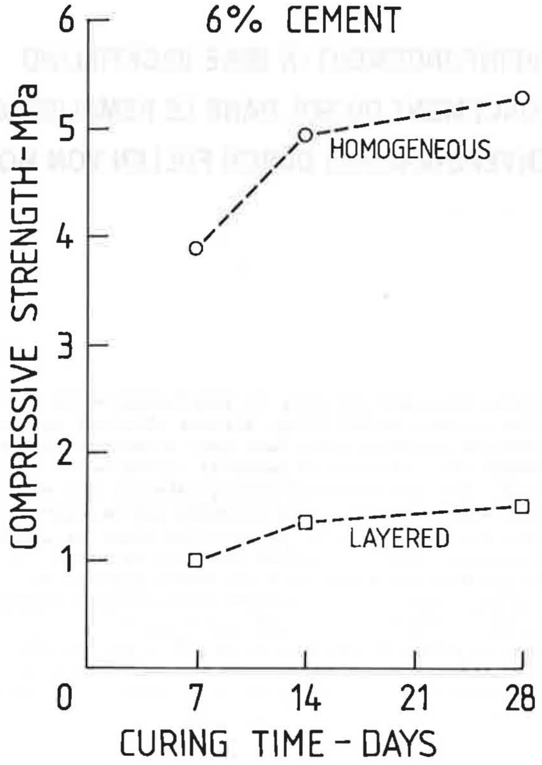


Figure 2 Curing characteristics of cemented samples

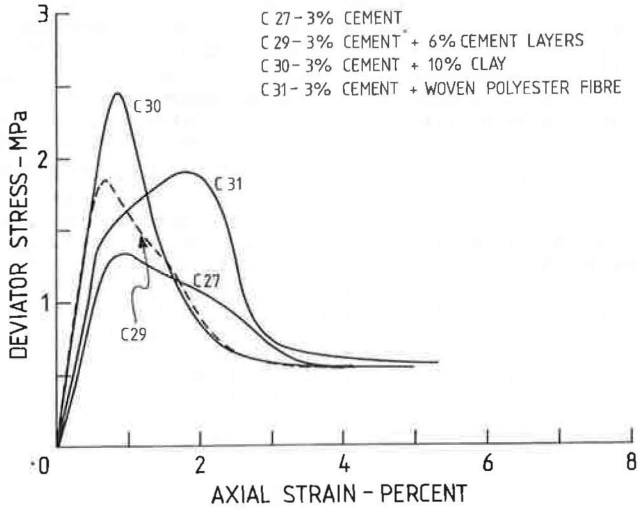


Figure 3 Effect of clay, woven polyester fibre and 6% cement discs on 3% cemented samples

The configuration of the specimens for direct shear tests are shown in Figure 4. Tests K12A and K22B were designed to simulate the failure characteristics obtained from the triaxial testing, and Test K22C was undertaken to provide a closer insight of shear strength behaviour of triaxial samples when the woven polyester fibre was deformed. The shear strength behaviour at the soil-reinforcement interface was found to be different from the global behaviour of reinforced soil. Cohesion and internal friction angle were shown to be higher in the latter case than at the soil-reinforcement interface. The results also revealed that shear strength decreased as the reinforcing element was deformed or broken.

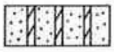
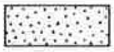
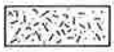
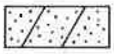
TEST N°	MATERIAL	DESCRIPTION
K 10	6% CEMENT	
K 10 A	6% CEMENT	
K 12	6% C VS. SAND	
K 12 A	6% C & SAND	
K 14	SAND	
K 18	FIBERMESH & SAND	
K 20	FIBERMESH VS. SAND	
K 22 A	WOVEN POLYESTER FIBRE VS. SAND	
K 22 B	WOVEN POLYESTER FIBRE & SAND	
K 22 C	WOVEN POLYESTER FIBRE & SAND	

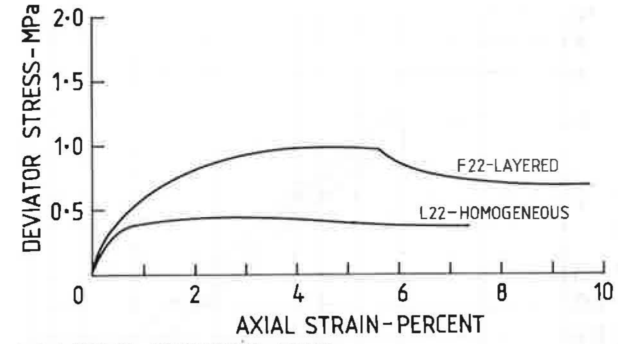
Figure 4 Configuration of direct shear test specimens

4 FACTORS AFFECTING THE BEHAVIOUR OF REINFORCED SANDFILL

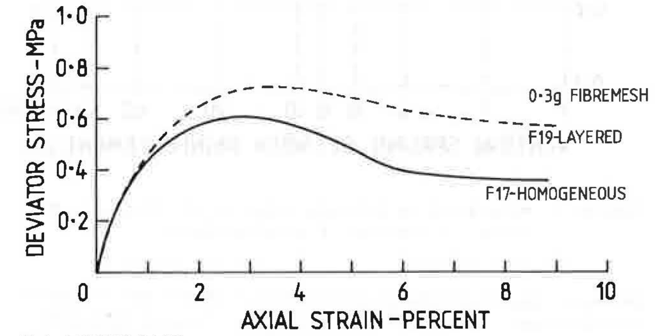
4.1 Type of Reinforcement

Whereas cement was used as a chemical reinforcing agent, woven polyester fibre and fibermesh were employed as mechanical reinforcing. It was noted that there was a marked decrease in strength when the cement was confined in layers rather than mixing with sand homogeneously (see Figure 2). It was thus of interest to determine the feasibility of using randomly oriented discrete fibres as a soil inclusion to improve the properties of the soil. Accordingly, an equal amount of three layers of woven polyester fibre was cut into 10 mm strips and mixed with the soil. As depicted in Figures 5a, a decrease in both compressive strength and strain at failure were observed when the polyester fibre was randomly distributed through the sample. This demonstrated that the reinforcement in the form of layers provided tensile strength to the soil mass and enabled it to accept larger strain without loss of stability. Similar results were also noted in the case of fibermesh-reinforced samples (Figure 5b).

Without the introduction of a pre-determined shear band former, some samples failed in a bulging manner between the reinforcing layers. This suggested that a peripheral reinforcement in addition to the horizontal reinforcement may enhance the strength performance. Figure 6 shows the stress-strain behaviour of samples with woven polyester fibre as peripheral reinforcement. It is observed (by comparing with Figure 5a) that samples with peripheral reinforcement as well as horizontal reinforcement exhibited substantial increase in strength compared with horizontal reinforced samples. Thus peripheral reinforcement can be used either as an alternative or an additional effort to strengthen the granular material.



(a) WOVEN POLYESTER FIBRE



(b) FIBERMESH

Figure 5 Stress-strain behaviour of samples with mechanical reinforcements

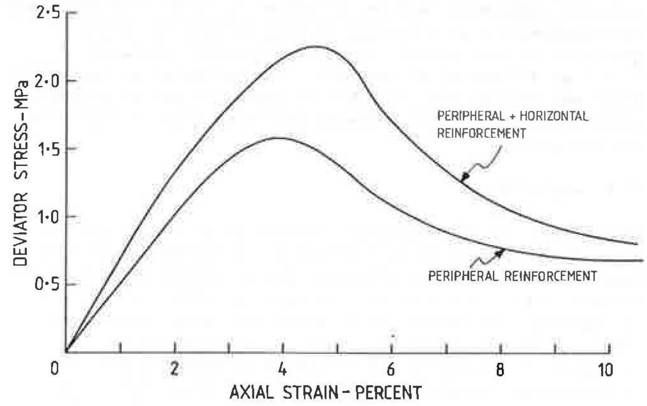


Figure 6 Effect of peripheral reinforcement on strength performance

4.2 Concentration of Reinforcing

Cemented layers and woven polyester fibre were used to investigate the effect of increasing the number of reinforcing layers on compressive strength. As illustrated in Figure 7, a linear relationship was obtained when the compressive strength was plotted against the

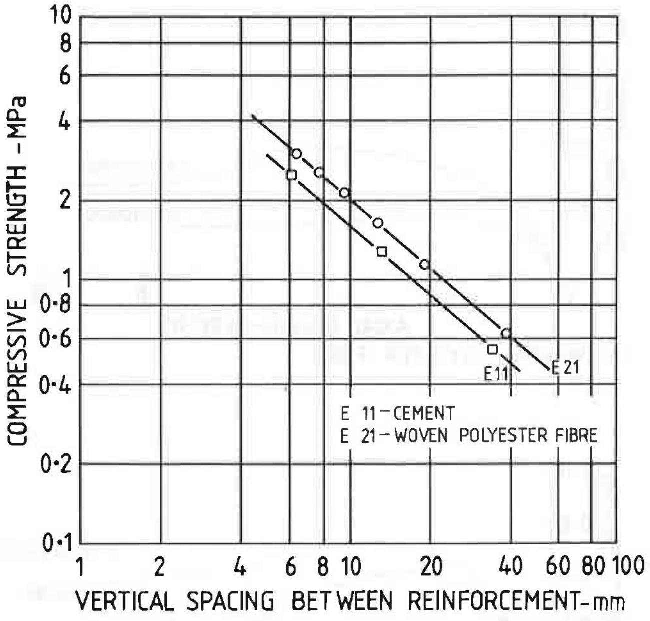


Figure 7 Relationship between compressive strength and vertical spacing of reinforcement

vertical spacing between reinforcing layers on a double-log diagram. This indicates that the failure strength is inversely proportional to the vertical spacing of reinforcing layers.

In order to examine the influence of reinforcing layer thickness on compressive strength, double and triple layers of woven polyester fibre were used in each reinforcing layer. The layers were joined together with fine copper wires to avoid sliding between layers. Test results indicated that an increase in layer thickness was accompanied by an increase in compressive strength. However, it was noted that high fibermesh content (~0.5 g) in layers would lead to a decrease in strength. This was due to the increase in porosity which occurred with increasing reinforcement and thus gave a reduction in strength.

4.3 Segregation

Model testing of placement conditions at Mount Isa, Australia, showed that segregation occurred vertically due to different particle settlement rates in pools of excess drainage water(1). It was therefore of value to examine the effect of segregation on strength and to find out the location of reinforcing element in segregated samples which resulted in maximum strength. Accordingly, samples were tested with the configuration as shown in Figure 8, wherein uniform sized fine and coarse particles were introduced in the mid-section of the samples. In terms of compressive strength, it was found that there is no significant difference between segregated and homogeneous samples (see Figure 9). However, with the introduction of a reinforcing layer in the mid-section, there was a pronounced increase in strength for samples with the reinforcing element embedded in the fine particle region. This was evidently due to the higher frictional resistance between the reinforcement and the fine soil particles than with the coarse materials.

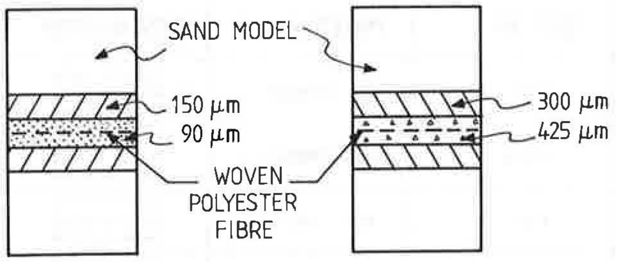
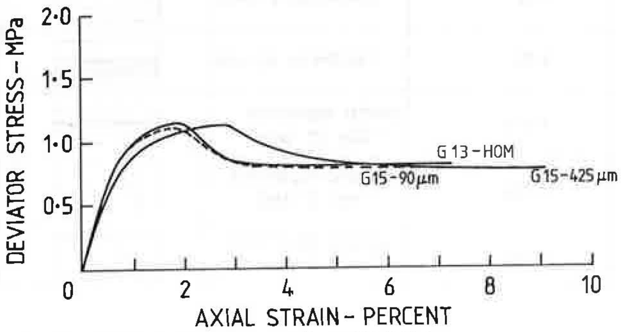
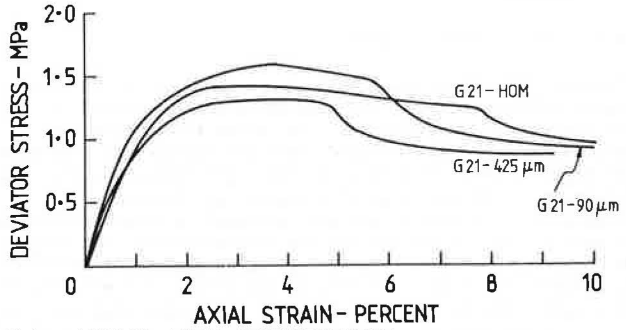


Figure 8 Configuration of segregated samples



(a) SAMPLES WITHOUT REINFORCEMENT



(b) SAMPLES WITH REINFORCEMENT

Figure 9 Effect of reinforcement on segregated samples

4.4 Moisture Content

It was apparent that the moisture content of the specimen at the time of test had a bearing on the compressive strength(2). Cemented samples were therefore prepared with various moisture contents and cured for 28 days before testing. As illustrated in Figure 10, it was observed that the compressive strength of both cemented samples and samples reinforced with woven polyester fibre decreased with an increase in moisture content. This also conforms with the results of the unreinforced sand samples.

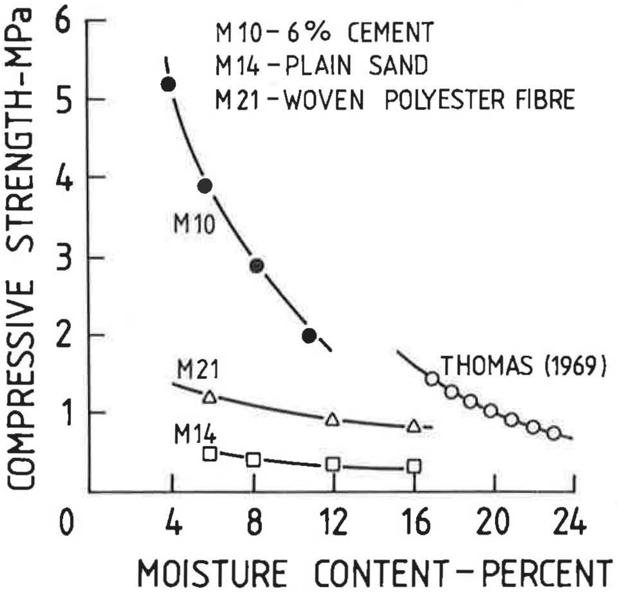


Figure 10 Variation of strength with moisture content

5 CONCLUSIONS

Various mechanical reinforcing agents have been employed to study the feasibility of improving the performance and strength of mine backfill using reinforcement techniques. The failure characteristics of the reinforcements suggest that the desired reinforcing material not only has to possess substantial tensile strength and be non-corrosive, but also needs to have the ability of interacting with the sandfill material through apparent cohesion and friction. This would improve the global strength of the fill mass as well as enabling it to undergo large strain before failure.

A chemical reinforcing agent such as cement appears to provide higher compressive strength than using mechanical reinforcement. However, the strength depends significantly on the cement content, curing duration and moisture content. An addition of clay material or inclusion of reinforcing layers would further enhance the cemented fill performance. The former would increase significantly the cohesive strength of the fill material whereas the latter would improve the internal friction angle. Homogeneous cemented samples were noted to have higher strength than the corresponding layered samples, and the contrary applies for mechanically reinforced samples. This is evidently due to the requirement of tensile strength if the reinforcing element is used according to the principles of earth reinforcement. Tests with peripheral reinforcement demonstrated an alternative to improve the strength performance.

Compressive strength was found to increase with increasing thickness of reinforcement, or with decrease in vertical spacing of reinforcement and moisture content. Tests with segregated samples suggested that reinforcement is best embedded in the fine particle region where the frictional resistance is apparently higher with fine granular soils than with coarse materials. Direct shear test results also demonstrated the global behaviour of the reinforcing mechanism. It further revealed the shear strength behaviour of the reinforcing system at failure and at the soil-reinforcement interface. From the strength performance of mechanical reinforced samples, it would seem that the mechanical reinforcement techniques may be more applicable in shallow mining wherein a stepwise stope extraction method is utilised.

6 ACKNOWLEDGEMENTS

The author would like to thank Mr. D.R. Willoughby for his helpful advice and discussion. The assistance of Mr. M. Leach in the experimental phase of the work is also greatly appreciated.

7 REFERENCES

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