Fly Ash - Geosynthetic Interaction

M. R. Hausmann & J. Clarke
University of Technology, Sydney, NSW, Australia

ABSTRACT: Fly ash from Vales Point Power Station in New South Wales was tested with respect to its suitability for the construction of geosynthetic reinforced embankments and retaining structures. Fly ash may be corrosive for metal reinforcement, hence the choice of geogrids and geotextiles as tensile reinforcement. Direct shear tests and pull-out tests indicated that ash is suitable as a fill material for geosynthetic reinforced structures. Filtration tests showed that conventional geotextiles on their own may not be able to retain all ash particles and further studies of this problem are recommended.

1 INTRODUCTION

This paper presents the results of a comprehensive investigation into the interaction characteristics of a specific material (fly ash) with a range of geosynthetics with respect to reinforcement as well as drainage and filtration.

Fly ash from Vales Point Power Station in New South Wales was tested with respect to its suitability for the construction of geosynthetic reinforced embankments and retaining structures. Fly ash may be corrosive for metal reinforcement, hence the choice of geogrids and geotextiles as tensile reinforcement. Geotextiles may also serve to control internal and external erosion.

In geotechnical terms power station fly ash is classified as a sandy silt or silty sand. Australia produces some 8 Million tonnes annually. Only some 10% are used for constructive purposes, the rest is disposed of hydraulically in reservoirs or in a moist (conditioned) state in landfills. Geosynthetics open up new opportunities for fly ash to become a construction resource rather than a waste product, with corresponding economic and environmental benefits.

Fly ash/geosynthetic friction was initially evaluated using a small size and a medium size (300*300 mm) shear box. These results were complemented with pull-out tests from a large box (600 mm wide by 1000 mm long) filled with ash and subjected to vertical pressures applied pneumatically.

In order to evaluate drainage and filtration requirements, several geotextiles were subjected to dry sieving, wet sieving and hydrodynamic filtration tests with fly ash. In addition, gradient ratio tests were performed.

2 MATERIAL PROPERTIES

2.1 Fly Ash

According to the Unified Soil Classification System fly ash from Vales Point (N.S.W.) has a group symbol ML or SM and can be described as a sandy silt or silty sand. Typical average properties are:

Max. dry density (Std. compaction) = 1.10 t/m^3
Max. dry density (Mod. compaction) = 1.16 t/m^3
Opt. moisture content (Std. compaction) = 32 %
Opt. moisture content (Mod. compaction) = 25 %
Internal friction angle = 33 deg.
Initial stress-strain modulus (triaxial test) = 30 MPa
Stress-strain modulus (plate load tests) = 100 MPa
Modulus of subgrade reaction k_s
(300 mm diameter plate) ≥ 130 kPa/mm
California Bearing Ratio (CBR), unsoaked = 33
California Bearing Ratio (CBR), soaked = 12
Texas Triaxial Test Class = 4

The above strength and compressive properties resemble those of a medium to dense sand; but the unit weight of this ash after compaction is only about 60 % of that of a dense sand. It should be noted, however that fly ash is less permeable than sand (say $k < 10^{-7}$ m/s), has no real cohesion in the short term (only apparent cohesion if unsaturated), and is highly erodible, at the surface and internally.

The low unit weight and a relatively high friction angle are two properties which make fly ash attractive as a fill for reinforced soil structures. The low unit weight produces less foundation settlement and lower earth pressures (thus requiring less reinforcement) than ordinary soil backfills. An additional benefit is that in the long term pozzolanic reactions tend to increase the strength of fly ash. Using synthetic geogrids as reinforcement avoids any problem of corrosion.

2.2 Geosynthetics

The direct shear and pull-out testing program, which is still in progress, involves a number of different geogrids. The results presented here concern Tensar geogrids (punched and drawn sheets of polypropylene) and Paragrid (intersecting flat strips of polyester fibres encased in polyethylene).

Filtration tests were carried out using a variety of geotextiles. The results presented here pertain to Bidim products and Terram 1000 with Equivalent Opening Sizes between 130 and 200 microns.

3 TEST PROCEDURES AND RESULTS

3.1 Shear box tests

In the 300*300 mm shear box the fly ash was compacted in three layers when tested for the internal friction angle ϕ, and two layers when tested for the skin friction angle δ with the geosynthetic. The density of the compacted ash was controlled by compacting a predetermined amount of wet ash into the shear box until the desired height was achieved. Densities from 96% to 100% of the Standard Proctor density were achieved.

For the fly ash/geogrid testing the geogrid was glued to a plywood board and placed flush with the top of the lower half of the box. Coarse sand was glued onto the board between the grid elements. This was done in order to make certain that shear within the area of the geogrid openings occurred in ash rather than between the ash an plywood.

The rate of shear was kept constant at 1.0 mm/min. This rate was chosen to reflect other work by Boot (1990), Bergado *et. al.* (1992) and Jones *et. al.* (1990).

A series of standard or "multiple set-up" tests as well as stage tests or "single set-up" tests were performed.

A typical result of a stage test is shown in Fig. 1.

Stage testing is less time-consuming, requires less material and sample conditions such as density and moisture content remain constant throughout. However, the second and subsequent stages do not produce a peak shear strength, only the ultimate or residual value (Hausmann and Clarke, 1994, and Bemben and Schultze, 1993). Results as given in Table 1 and Table 2 indicate that the difference between peak and residual shear strength parameters depends on the type of geogrid involved. These tables give the internal friction angle ϕ of the ash, the average ash/geogrid interface friction angle δ, and the corresponding cohesion c and average adhesion c_a.

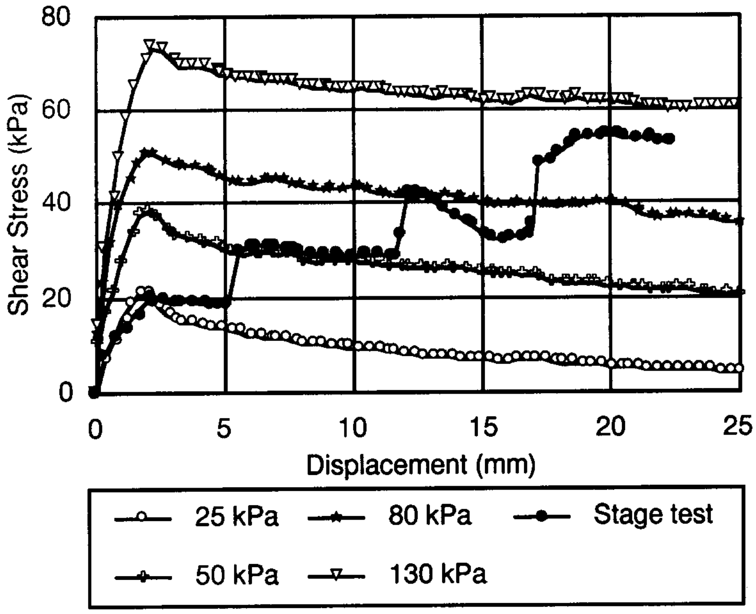

Fig. 1 Direct shear test of fly ash on Tensar SR110

Table 1 Peak shear strength parameters (Standard tests)

Test material	Standard tests (Peak values)	
	ϕ or δ (°)	c or c_a (kPa)
Fly ash alone	39.7	10.4
Tensar SR110	25.7	11.7
Tensar SS2	30.0	8.2
Paragrid 100/25s	26.9	3.6

Table 2 Residual shear strength parameters (Standard and stage tests)

Test material	Standard tests Residual values		Stage tests	
	ϕ or δ (°)	c or c_a (kPa)	ϕ or δ (°)	c or c_a (kPa)
Fly ash alone	28.1	3.2	28.4	4.8
Tensar SR110	24.0	5.8	20.3	12.6
Tensar SS2	27.5	1.9	27.7	3.4
Paragrid 100/25s	26.9	0	24.1	2.6

3.2 Pull-out tests

The pull-out tests were performed on a purpose-built reaction frame. The test box was 1000 mm long, 600 mm wide and 750 mm high. The fly ash was compacted in eight layers using an electric jackhammer, to a density equivalent to 96% to 99% of the standard maximum dry density. Three layers of reinforcement were installed in each box, at 150 mm vertical spacing.

The vertical pressure was applied to the top of the ash by means of a pair of industrial type air bags sandwiched between two sheets of plywood. Typically, the pull-out tests were carried out at vertical pressures of 19 kPa, 41 kPa and 78 kPa, in that order.

The geogrids were gripped outside the box by means of two steel plates bolted together and connected to a loading yoke. A load bolt was incorporated in the loading system to electronically record the pull-out force. The pulling force was produced by a hydraulic jack operated with a hand pump.

All instrumentation was zeroed after a 2 kN seating load was applied to the geosynthetic. The pull-out load was raised smoothly and continuously until sliding or rupture of the geogrid occurred. The rate of pull-out was approximately 1 mm/min.

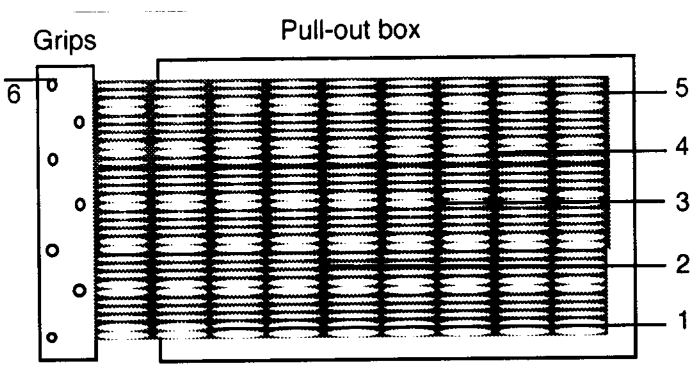

Fig. 2 Rotary pot attachments.

Strings were attached to five points on each grid, as shown in Fig. 2. The movement of these points could then be recorded with rotary potentiometers.

The results are firstly presented in form of diagrams showing grip displacement vs. pull-out force at different overburden pressures. Secondly, the mobilisation of tension in the grid with increasing pull-out force is illustrated with diagrams showing the displacement of the five measuring points on the grid during the test.

Fig. 3 gives the grip displacement vs. pull-out force for Tensar SR 110. Fig. 4 shows the movement of the instrumented grid points for the tests at 19 kPa vertical pressure for each of this grid.

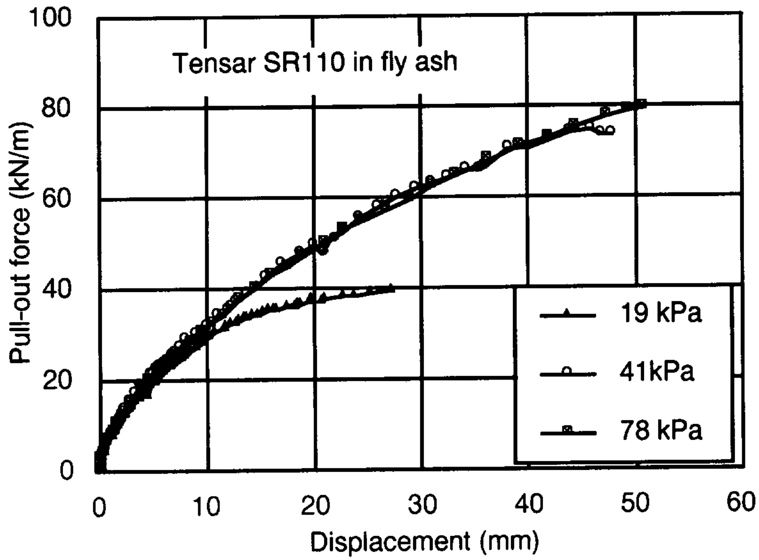

Fig. 3 Pull-out force vs. displacement for Tensar 110 in fly ash

3.3 Filtration tests

A majority of the particles of fly ash are in the silt size range. Initial dry sieving and wet sieving tests indicated that there is a problem in containing these particles with conventional geotextiles. In order to investigate this problem a series of gradient ratio tests and hydrodynamic sieving tests were carried out.

The gradient ratio tests were performed generally according to ASTM D 5101-90. The diameter of the specimen within the apparatus was 108 mm, the total length 100 mm. Fig. 5 shows the results obtained with three different geotextiles over a test period of 74 hours. For the first 24 hours a hydraulic gradient of one was applied. The gradient was then increased to five for the next 24 hour period, and finally a gradient of 10 was applied. Each of the three curves plotted represents the average result of two or more tests. The system permeability varied between $1x10^{-6}$ to $3x10^{-6}$ m/s, showing a small increase during the test period.

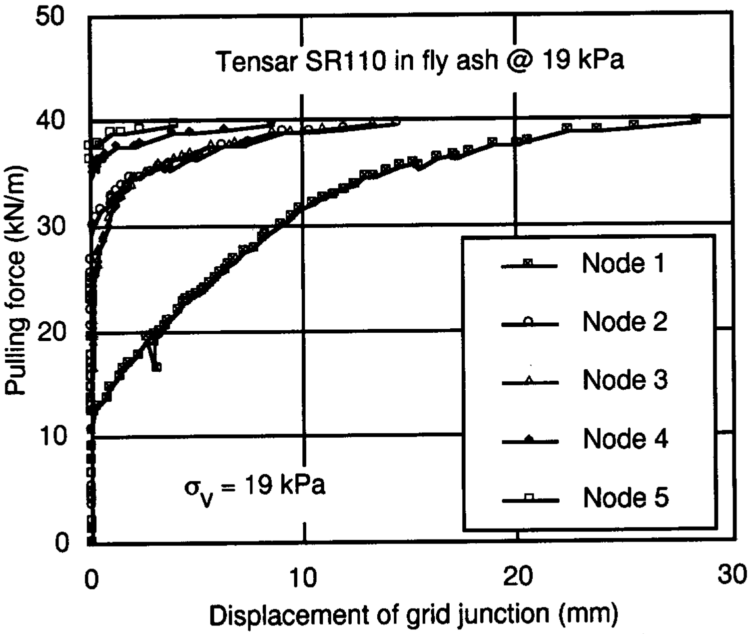

Fig. 4 Node displacement of Tensar 110 in fly ash at a surcharge load of 19 kPa.

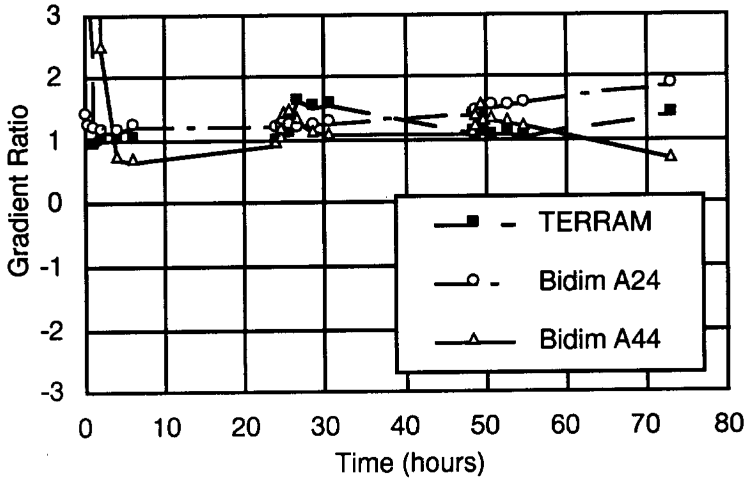

Fig. 5 Gradient ratio vs. time

The hydrodynamic sieving test is normally used to determine the opening size of a fabric for hydrodynamic flow conditions. The test soil is wrapped in the geotextile being evaluated and immersed and withdrawn from water approximately 2000 times over a 24 hour period. Particles finer than the fabric openings are washed out by this procedure. Fig. 6 presents the original grain size distribution of the fly ash and of each of the fractions which was washed through different Bidim fabrics.

4 DISCUSSION

Direct shear tests yield an average ash/geogrid interface friction and adhesion. Some geogrids exhibit a significant peak on the shear stress-displacement diagram, others do not.

Pull-out tests give an indication of the length of geogrid required to resist pull-out under a specific overburden pressure. Measurement of the displacement of nodes within the geogrid tested indicates how the pull-out resistance is mobilised along the grid. It was attempted to plot the tensile force in the grid as a function of the distance from the front face of the box. However, the results were somewhat erratic, unlike similar tests carried out by the authors with sand fill, or earlier by Ochiai et al (1992). The development of tension in the grid with increasing pull-out force was more regular with Tensar than with Paragrid. As some of the welded connections of the Paragrid yielded, the tension in the longitudinal strips became uneven and the node movements became irregular. Further tests are in progress in order to provide better information for the mathematical analysis of geogrid reinforced ash structures.

The gradient ratio of fly ash combined with Bidim A24, Bidim A44 and Terram was predominantly in the range of one to two. From these results it can be concluded that clogging is certainly not a problem. These relatively short term tests look promising as far as the control of piping is concerned but the fact that the gradient ratio does drop below one for the heaviest fabric tested indicates that further evaluation is warranted. It should be noted that none of the fabrics tested satisfies the Giroud retention criteria when applied to fly ash.

The hydrodynamic sieving indicated that the majority of the fly ash particles are washed through the fabric under reversing flow conditions where no filter zone is allowed to be established. However, the results indicate that the thicker a non-woven fabric is, the finer is the material which is washed out of the original fly ash over the test period.

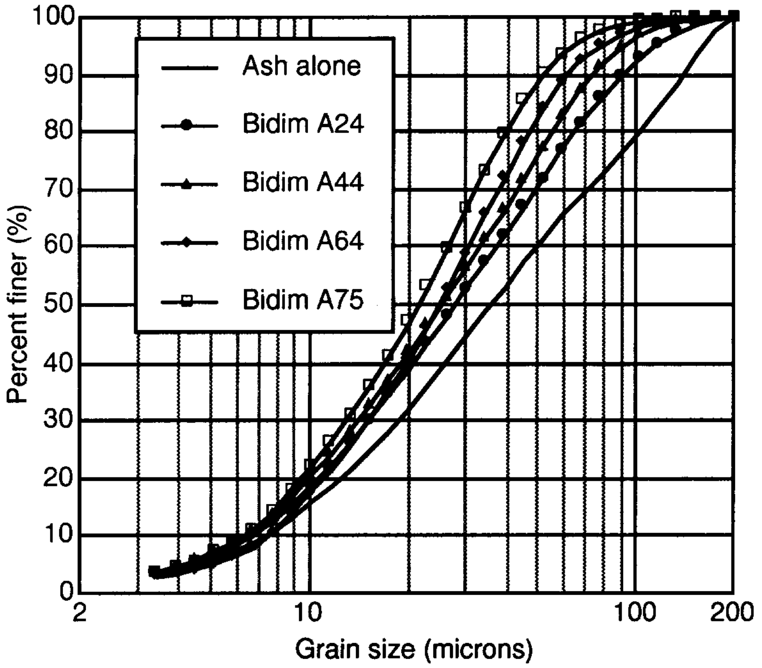

Fig. 6 Grain size distribution curves of fly ash before and after hydrodynamic sieving

5 CONCLUSIONS

Direct shear tests yield minimum ash/geogrid shear strength parameters. They can be used to analyse wedge type failures involving sliding of ash on the reinforcement. Stage tests are an economical means of determining residual shear strength parameters for the materials used.

The pull-out tests yielded basic information for the stability analysis of a geogrid reinforced ash structure. However, additional tests will be carried out in order to improve the information gained on the mobilisation of the pull-out resistance along the grid. Both, direct shear as well as pull-out tests indicated that high values of friction are developed between ash and geosynthetic reinforcement.

Filtration tests confirmed that the protection of ash against internal erosion is a problem which could affect fly ash in segmental wall systems. Longer term filtration tests are needed to properly assess whether thick non-woven fabrics are sufficient to prevent piping or whether the fabrics should be complemented with a granular filter layer, such as bottom ash or sand.

ACKNOWLEDGEMENTS

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