Earth Reinforcement Practice, Ochiai, Hayashi & Otani (eds) © 1992 Balkema, Rotterdam. ISBN 90 5410 093 1

Geosynthetic reinforcements subjected to bi-directional stress An experimental study

D.I.Bush
Netlon Limited, Blackburn, UK

W.Böhmert
Bundesanstalt für Materialforschung und -Prüfung, (BAM), Berlin, Germany

ABSTRACT: Designers often rely on load-strain properties of geosynthetic reinforcement derived from uni-directional testing, even when designing for applications in which the geosynthetic is subjected to bi-directional stress. A series of tests have been carried out to investigate the effects of bi-directional stress on the performance of geosynthetic reinforcement and to compare this with the results of uni-directional tests on the same reinforcement. Critical failure mechanisms have been identified. The results suggest that there is a variation in performance and it is recommended that where geosynthetics are to be subjected to bi-directional stress fields they should be tested in biaxial mode prior to their application.

1 INTRODUCTION

In many Civil Engineering applications a geosynthetic reinforcement is assumed to carry load in one direction (conditions of plane strain) so results from uni-directional tensile tests are useful in the design. However there are many practical applications, such as support over sub-surface voids or spanning between pilecaps, where external loading

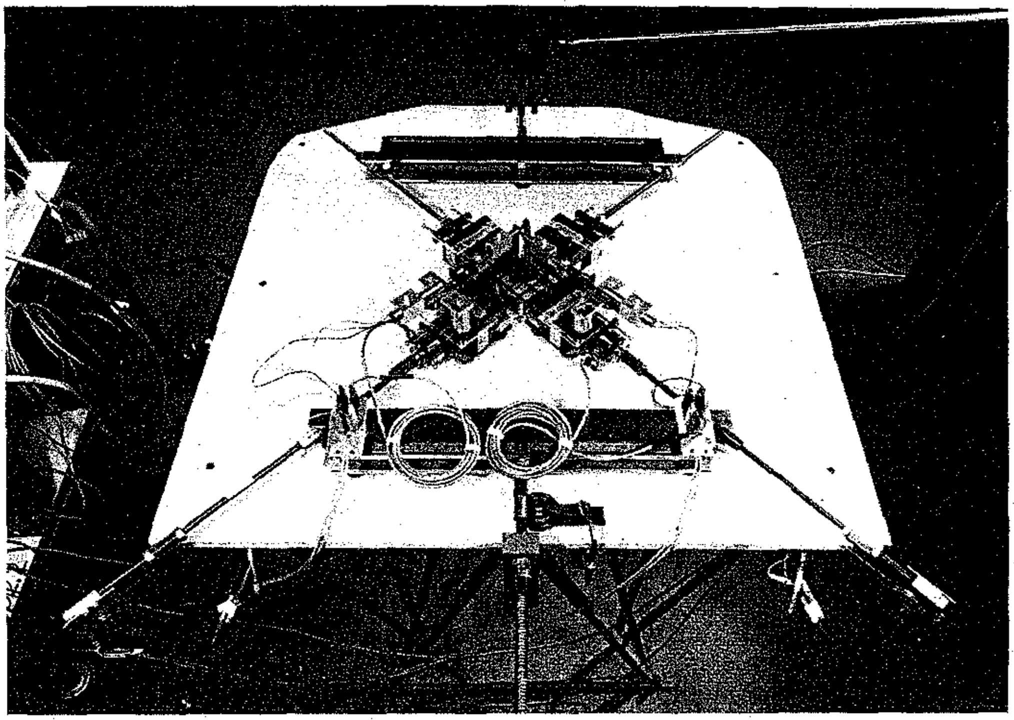

Figure 1: Biaxial tensile test machine

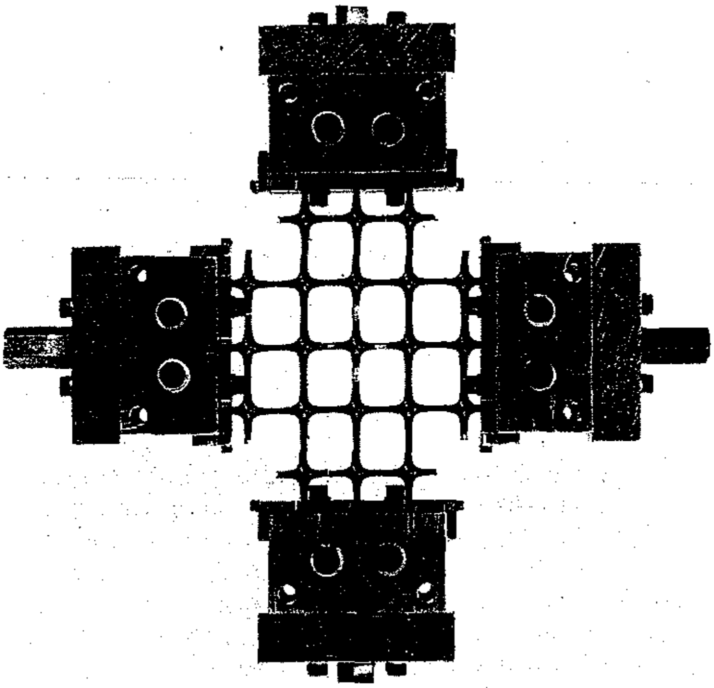

Figure 3: Three rib cross specimen in their closed clamps and revolving couplers

imposes biaxial stresses on a geosynthetic reinforcement.

In 1977, Böhmert began an investigation into premature failures of coated fabrics which were subjected to biaxial stresses in load bearing aerial structures. He found that the uni-directional tensile test data for these fabrics was inadequate to describe their bi-directional behaviour.

This paper describes test equipment which has been devised so that biaxial stresses can be applied simultaneously to specimens of geosynthetic reinforcement. Tensile tests were carried out firstly by applying the load uniaxially in each principal direction of the reinforcement and then biaxially.

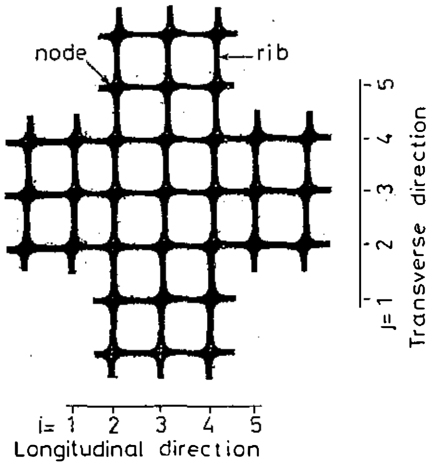

Figure 2: Three rib cross specimen co-ordinate system

2 TEST EQUIPMENT & PROGRAMME

The biaxial tensile test machine was developed during an investigation into the behaviour of coated fabrics used in load bearing aerial structures by Böhmert (1981). This machine, shown in Figure 1, permits unrestrained deformation of a biaxially loaded area of a cross-shaped specimen. The two cross-heads move on roller bearings together with four tensile rods which, when a force is applied at the corresponding points on the cross-heads, load the geosynthetic test specimen through specially shaped jaws designed to minimise slippage and avoid premature jaw initiated failure of the specimen.

The biaxial tensile test machine is capable of applying loads to geosynthetics whose warp and weft directions could lie between 77° and 103°. The differences in fracture strains between the warp and weft directions of

Table 1: Summary of test programme and results

Test and Specimen Size	Load (kN/rib)	Central Strain Long %	Central Strain Trans %	Total Strain Long %	Total Strain Trans %	Elongation at node	Failure at node
Uniaxial test	0,5	-	1,7	-	2,6	(3,2)	(3,2)
transverse rib	1,0	-	6,2	-	8,5	to	
max load	1,20	-	17,3	-	17,5	(3,4)	
Uniaxial test	0,5	2,0	-	2,7	-	(2,3)	(3,3)
longitudinal rib	1,0	6,8	-	8,5	-	to	
max load	1,15	29,6	-	25,8	-	(2,4)	
Biaxial test	0,5	1,7	1,9	2,8	2,6	(2,3)	(2,3)
single cross rib	1,0	5,0	5,1	8,4	7,3		
max load (long)	1,17	7,0	6,8	16,8	10,3		
Biaxial test	0,5	1,9	1,7	2,5	2,5	(1,2)	(1,2)
three ribs cross	1,0	5,2	4,8	7,1	6,2	and	
max load (long)	1,18	7,2	6,2	11,8	8,9	(5,4)	

geosynthetics can depend on the nature and degree of orientation of the polymer and this could result in variations of their non-linear visco-elastic load-strain behaviour. Thus each cross-head is capable of producing different, accurately controlled cross-head speeds simultaneously in both warp and weft directions.

The machine can replicate practical loading conditions in stretched fabric load bearing aerial structures and geosynthetic reinforced soil applications where the applied load ratios are continuously variable from 1:5 through 1:1 to 5:1 and the chosen ratio will remain constant throughout a test. In this test series the load is applied at a constant rate of strain of 10% per minute. Constant strain rate is controlled by feedback from electrical displacement transducers positioned on each side of the central stressed area (Figure 1). Load is measured by electrical cells and overall jaw displacement is also recorded.

The applications of particular interest in the experimental study were geosynthetic support over mining voids and spanning between pile caps supporting an embankment. Tensar SS35 geogrid is most frequently used for these applications and the test programme was therefore designed to compare its load/strain and fracture under uniaxial loading and symmetric biaxial loading. For uniaxial tests, single rib wide by three nodes long specimens were sampled from both longitudinal (machine) and transverse directions of Tensar

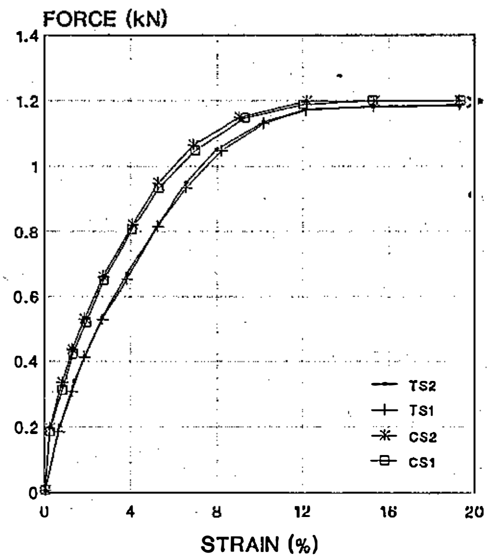

Figure 4: Uni-directional tests on Tensar SS35 geogrid transverse rib - Force/Strain curves

SS35 geogrids.

For biaxial tests, two sizes of cross-shaped specimens were sampled:- i) a simple single rib, five nodes long in each direction, ii) three ribs wide, seven nodes long in each direction (Figure 2).

A co-ordinate system was set up (Figure 2). The free nodes of the clamped specimens (Figure 3) were highlighted with white painted circles to assist observation and definition of failure behaviour.

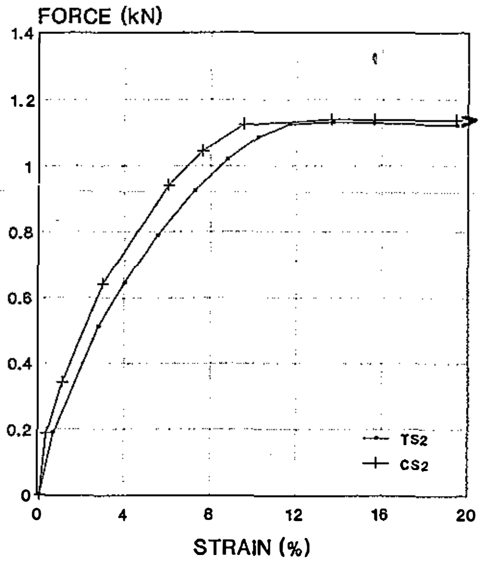

Figure 5: Uni-directional tests on Tensar SS35 geogrid longitudinal rib - Force/Strain curves

3 RESULTS

To enable direct comparison to be made between 1 and 3 rib wide specimens, all results are reduced to load per rib and strains are expressed as a percentage. A summary of the test programme and results is shown in Table 1.

3.1 Uni-Directional Tests

Uniaxial load-strain curves are shown in Figures 4 and 5 for the transverse and longitudinal ribs respectively. Repeat test data is shown for the transverse direction only and is omitted for clarity on the other tests.

Typical failure of the uniaxial ribs is shown in Figure 6 and the elongated areas were circles at the start of the test.

3.2 Bi-Directional Tests

Biaxial load-strain curves for the single rib cross specimen test showing central and overall strain are given in Figure 7. The failure mode is shown in Figure 8.

Three rib cross specimen bidirectional load-strain curves are shown in Figure 9.

The failure mode is shown in Figure 10.

4 DISCUSSION

The force-strain curves from the uni-directional tests, Figures 4 and 5, shown characteristic visco-elastic behaviour of an oriented polypropylene until peak load is reached. Beyond this there is post peak yield during which peak load remains constant and the long chain

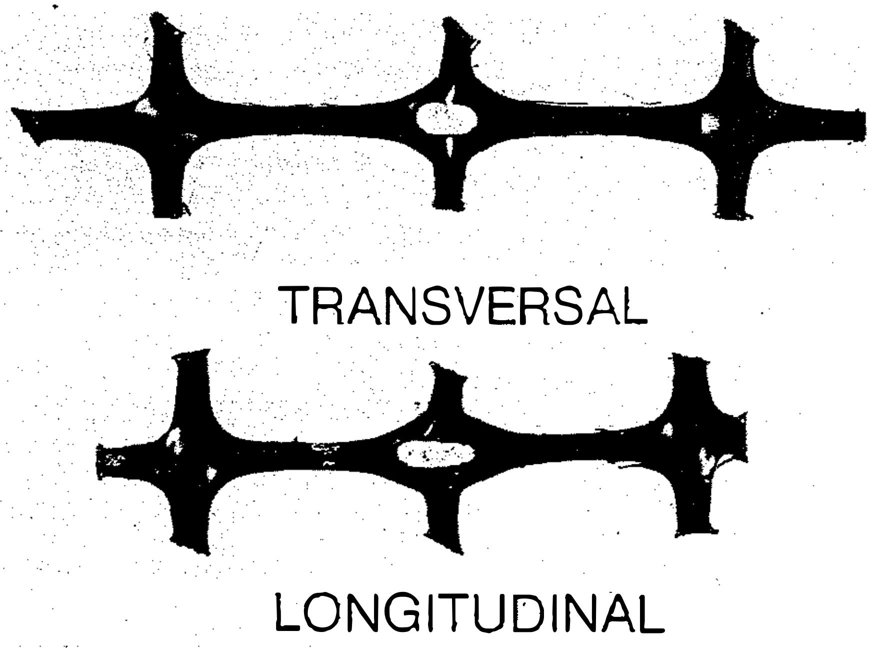

Figure 6: Typical failure of uni-directionally stressed ribs

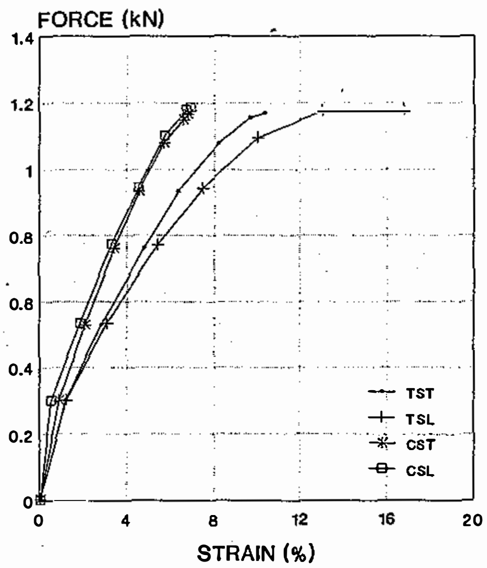

Figure 7: Bi-directional tests on Tensar SS35 geogrid - one rib cross with 1:1 load ratio - Force/Strain curves

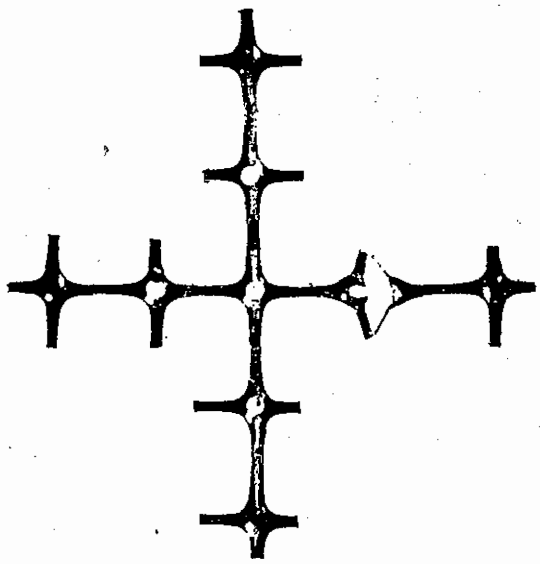

Figure 8: Typical failure of bi-directionally stressed one rib cross specimen

molecules continue to orientate. Peak load in the transverse rib direction was 1.2 kN, slightly higher than in the longitudinal rib direction at 1.15 kN. Peak load was first reached at around 10 to 12% strain.

In the early stages of the test there was a slight difference between measured central strain and total strain, indicating that there was probably some initial take up in the jaw region.

The force-strain curves Figure 4 show the results from two tests. These are in very close agreement, confirming the repeatability of the test method.

Observations of the specimen showed the normal failure mode of transverse and longitudinal single rib wide specimens. The node elongates and this lead to fracture across the node Figure 6.

The force-strain curves from the bidirectional tests on single rib cross specimen, Figure 7, shows visco-elastic behaviour up to peak load. The applied longitudinal and transverse strain rates are identical as is buildup of force in the two directions showing that the longitudinal and transverse rib stiffnesses of Tensar SS35 geogrid are the same.

Comparison with the uniaxial force-strain curves shows that the biaxial response is stiffer. Peak load is similar at 1.17 kN but there is post peak yield in one direction, ie. the direction of failure (longitudinal). Examination of the failed single rib cross specimen, Figure 6, shows the central node has remained undistorted but the failed longitudinal node has become elongated in the same way as the uniaxial specimen. The ribs of the other direction (transverse) have not entered the post peak yield phase.

The force-strain curves for the three rib-cross specimens under biaxial stress, Figure 9, are in very close agreement with the single rib biaxially stressed cross specimen. Peak load is reached at the same value of 1.17 kN/rib. The longitudinal direction again becomes critical and strains to failure. The failure mechanisms, Figure 10, appears at first sight to be more complex but on closer examination of the three rib specimens it is clear that the nodes 2.2, and 2.4 have elongated then fractured and this has led to a propagation of failure through the specimen. Re-examination of the failed single cross-specimen shows slight elongation of the intact nodes in the direction of applied load. The three rib cross specimen nodes have also elongated in the direction of applied load and the ribs have distorted into non-orthogonal configuration.

The transverse and longitudinal ribs have stretched and nodes have elongated so that the load is no longer transmitted axially through each of the ribs so has to rely on the strength and torsional resistance of the junction to transmit the load from rib to rib. This stress regime is typical of that which would occur in the practical conditions of support over a void or spanning between pile cap.

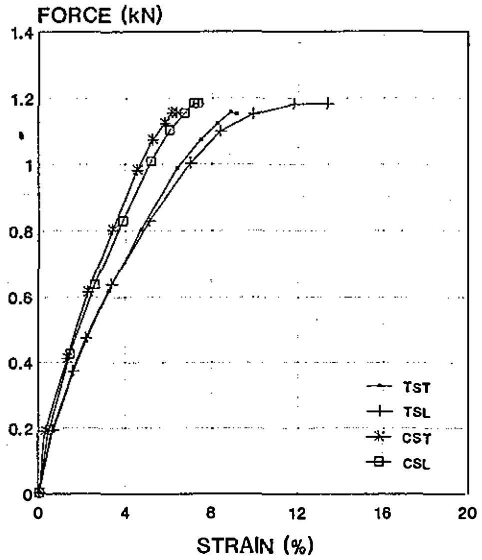

Figure 9: Bi-directional tests on Tensar SS35 geogrids - three rib cross with 1:1 load ratio - Force/Strain curves

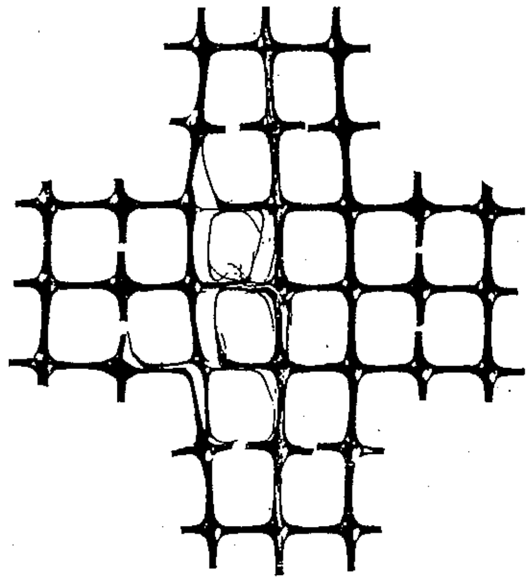

Figure 10: Typical failure of bi-directionally stressed three rib cross specimen

In his work on load bearing aerial structures, Böhmert (1981) tested a PVC coated panama weave made from high strength polyester fibre (1100 decitex, 60T/n) and found there was a reduction of 25% in the warp rupture strength from its uniaxial strength when it was tested under a symmetrical biaxial stress. In the weft direction the reduction was 7%. The coated panama weave behaved stiffer under biaxial stress so there was a larger reduction in strain to failure. No post peak behaviour was observed.

At the coated materials' working loads, around 25% of ultimate, Böhmert (1981) had found large differences between uniaxial and biaxial strains. These differences were particularly serious for a PTFE coated glass fibre cloth which failed at 30% of its uniaxial tensile strength with symmetrical biaxial stress.

In view of the variation in performance of these two geosynthetics, it is recommended that where these materials are to be subjected to biaxial load, they are tested in biaxial mode prior to their application.

5 CONCLUSIONS

5.1 The Tensar SS35 geosynthetic exhibited a stiffer load/strain response under biaxially applied loading than under unidirectional loading.

5.2 Biaxial loading distorts a rectangular specimen into non-orthogonal shapes. This causes additional stress raisers at the junction of longitudinal and transverse members and this effect must be fully evaluated. Tensar SS35 geogrid has stiff efficient junctions which were unaffected by these additional stress raisers.

5.3 Whilst the earlier work on coated fabrics had identified a reduction of peak strength of up to 25% under biaxial loading, the present work has shown that there is no change in the peak strength of Tensar SS35 geogrid under biaxial loading.

REFERENCES

Böhmert, W. 1977: Tragverhalten beschichteter Gewebe unter der Wirkung ebener Spannungzustände; Forschungsvorhaben, BAM VH 02206, Innenminister des Landes Nordrhein-Westfalen 72.02, Nr 31/73, Bundesanstalt für Materialprüfung (BAM) Berlin.

Böhmert, W. 1981: Prüfverfahren und -einrichtungen zur Ermittlung des Kraft-Dehnungsverhaltens zweiachsig beanspruchter beschichteter Gewebe für Membrankonstruktionen. Material und Technik Vol 3, pp 159-167.