Index Testing of the Junction Strength of Geogrids

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ABSTRACT: Geogrids consist of orthogonal sets of tensile bars with junctions at the points of cross-over of the bars. The stiffnesses of the two sets of bars may be very different or be similar, indeed one set of bars may be very much weaker than the other so that the geogrid may only effectively resist uniaxial loading. Thus two classes of geogrid reinforcements may be identified; uniaxial geogrids, which develop tensile stiffness and strength primarily in one direction, and biaxial geogrids which, develop tensile stiffness and strength in two orthogonal directions. However, apart from different stiffnesses and strength in orthogonal directions, geogrids may exhibit different forms of junctions. These junctions may have several functions, including maintaining the geometrical form of the structure during transport and installation; enabling stresses and strains to be transferred through the geogrid and from the soil into the geogrid, so called interlocking between the soil and the grid. To date, all junction test methods aim to determine Index, (quality control), properties. These tests are not necessarily related to the design (Performance) requirements of the geogrids. Thus in this paper, two junction strength Index tests are described and then related to the operational requirements of uniaxial and biaxial geogrids.

1 INTRODUCTION

Geogrids are produced in a variety of geometrical forms using a wide range of polymeric materials and numerous manufacturing techniques. Two classes of geogrid reinforcements may be identified; uniaxial geogrids, which develop tensile stiffness and strength primarily in one direction, and biaxial geogrids which, develop tensile stiffness and strength in two orthogonal directions. Uniaxial and biaxial geogrids exhibit markedly diverse behaviours and are employed in very different applications.

Another characteristic of geogrids is that they may possess different forms of junctions, including entangled, heat bonded, welded and integral junctions. For geogrids with entangled or integral junctions, the junctions usually lie along the central axis of the bars. Thus, for most loading conditions any forces passing through the junctions develop only shear in the material forming the junction. For geogrids with heat-bonded or welded junctions, the junctions are usually offset from the central axis of the bars. Thus, for some loading conditions torque forces may be applied to the junctions. As a result there can be a degree of rotation of the bars entering the junctions and tearing of one set of bars away from the other set, particularly at large deformations, Ziegler & Timmers (2004). Therefore, under some conditions junctions may be subject to both shear and torque forces.

In this paper, the differences in the nature of geogrids manufactured by different processes are identified. The different operational behaviours of these geogrids are then discussed. Details are given of two Index test methods for junction strength testing. Test results are presented, compared and related to the operational behaviours of different geogrid types.

2 GEOGRID TYPES

The load-strain behaviour of geogrids may vary significantly in two orthogonal directions. This is associated with variations in the material and geometrical properties of bars and junctions in these directions, Kupec & McGown (2004) and McGown & Kupec (2004).

Uniaxial geogrids usually exhibit a high stiffness in one particular direction and a very low to negligible stiffness in the other direction. The main function of the secondary cross-members and junctions are to provide geometrical stability during transport and installation, but they may also provide the possibility of interlock with the soil in which they are placed. Such uniaxial geogrids are intended for use in plane strain applications.

Biaxial geogrids exhibit stiffness and strength in two orthogonal directions. In these materials, the bars and junctions provide geometrical stability during transport and installation and almost always provide interlock with the soil in which they are placed.

Biaxial geogrids may be divided into anisotropic and isotropic biaxial geogrids. Anisotropic biaxial geogrids exhibit dissimilar stiffnesses in two principal directions. They are used in anisotropic loading conditions, i.e. where there is a primary and a secondary degree of loading/strain. Isotropic biaxial geogrids exhibit very similar stiffnesses and strengths in two orthogonal directions and are used in isotropic loading conditions, i.e. where there is almost an equal degree of loading/strain in orthogonal directions.

The operational behaviours of uniaxial and biaxial geogrids varies greatly and it is important to use appropriate types of geogrids for uniaxial, anisotropic and isotropic loading/strain situations.

3 JUNCTION TYPES AND THEIR BEHAVIOURS

The junction types now in use are entangled fibres or filaments, heat or chemically bonded, laser or microwave welded bars or integral junctions formed during the uniaxial or biaxial drawing of punched sheets. All types of junctions provide geometrical stability during transport and installation and to some degree enable interaction with the fill in which they are placed.

Geogrids formed with entangled or heat-bonded junctions generally only possess adequate junction strength to transfer stresses from one set of bars to another when they are subject to significant normal confining stresses.

Geogrids formed with welded or integral junctions most often exhibit sufficient unconfined junction strength to transfer stresses from one set of bars to another under either uniaxial or biaxial loading/strain conditions.

4 OPERATIONAL CONDITIONS

Most Geosynthetic Reinforced Soil Structures exhibit very small strains and loads under normal operational conditions. Long-term monitoring of full-scale structures and laboratory modelling of load supporting structures indicate that very small deformation levels in reinforcing elements are developed, Stolarski and Gartung (2001), Murate et al (2001) and Zornberg & Arriaga (2003).

The behaviour of junctions of both uniaxial and biaxial geogrids at these low operational strain levels is likely to be dominated by shear forces developed due to bearing stresses in front of the cross-members. Possibly at Serviceability Limit State conditions, and almost always at Ultimate Limit State conditions, the stresses and strains in Geosynthetic Reinforced Soil Structure are likely to be large. Thus under uniaxial and anisotropic loading/strain conditions, the behaviour of junctions is likely to be dominated by shear forces developed due to bearing stresses mobilised in front of the cross-members, combined with torque forces due to vertical displacement of the cross-members, Fig. 1a. However, for isotropic biaxial loading/strain conditions the behaviour of junctions is likely to be dominated by shear forces generated due to loads and strains in two orthogonal directions, Fig. 1b.

5 INDEX TESTING OF JUNCTION STRENGTHS

Two Index tests were employed to determine the junction strength of a range of geogrids. The first test was the well established test method developed by the Geotextile Research Institute [GRI] at Drexel University in the USA and the second, a newly developed test method at the University of Strathclyde in the UK, Kupec et al (2004).

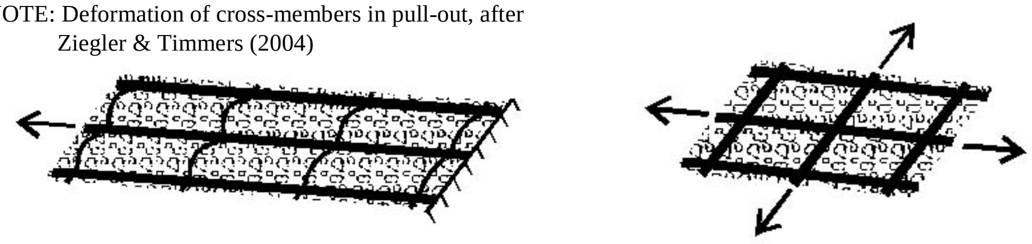
5.1 *GRI GG2 (1987) Test Method*

This test methodology for junction strength testing was developed at a time when the only geogrids exhibiting significant unconfined junction strength were integral junction geogrids. These have junctions in the same plane as the tensile bars. This test methodology was intended to provide Index (quality control) test data and not Performance (design) test data and is appropriate to the geogrids for which it was developed. Figure 2 shows the clamping arrangement used in this test method.

5.2 *Strathclyde Test Method, after Kupec et al (2004)*

This test methodology for junction strength testing was recently developed for geogrids with welded junctions, i.e. for geogrids possessing junctions which are not in the same plane as the tensile ribs. This test methodology was again intended only to provide Index (quality control) test data and not design (Performance) test data. The clamping arrangement is shown in Figure 3.

NOTE: Deformation of cross-members in pull-out, after Ziegler & Timmers (2004)



a) Pull-out behaviour in uniaxial loading/strain situations

b) Grid behaviour in isotropic loading/strain situations

Figure 1. Geogrid behaviour under isotropic and anisotropic loadings

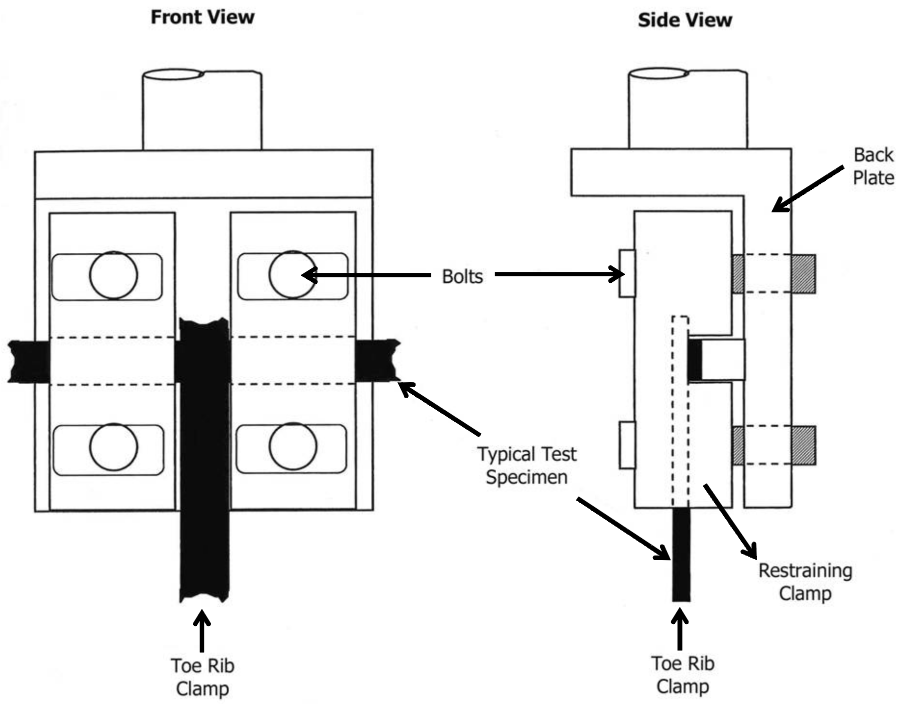


Figure 2. Clamping arrangements after GRI GG-2 (1987)

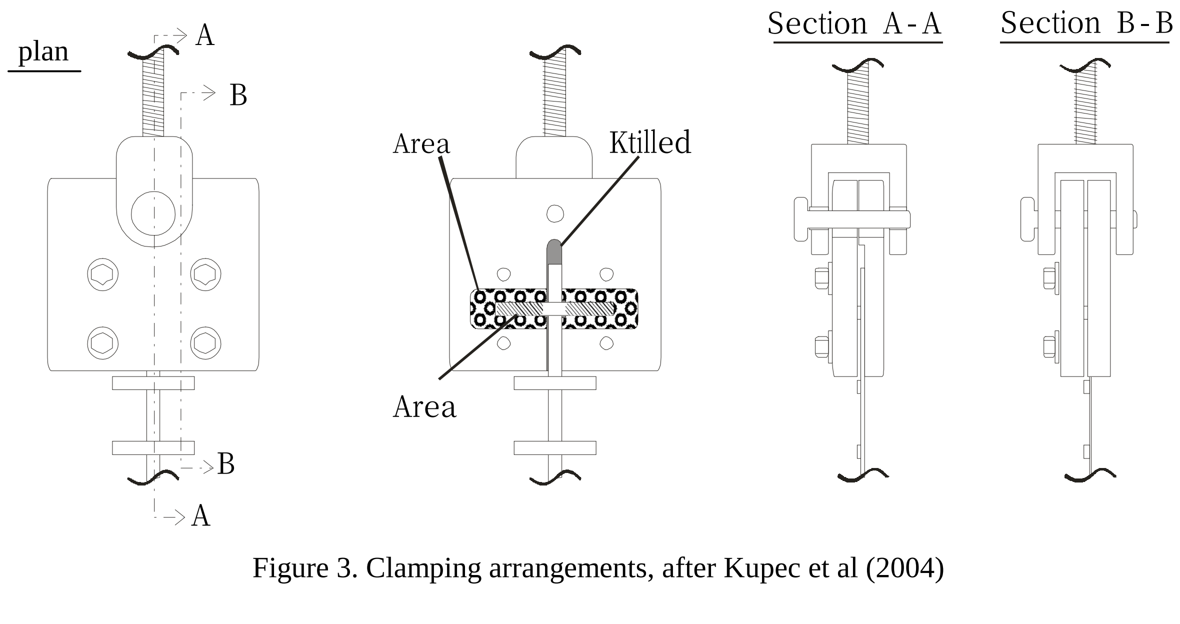
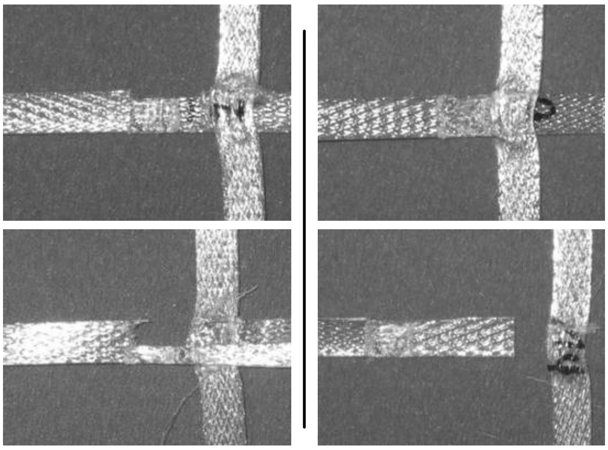


Figure 3. Clamping arrangements, after Kupec et al (2004)



(a) Junction Rupture (b) Shear displacement and separation

Figure 4. Modes of failure

Table 1. Properties of isotropic biaxial geogrids tested

Product Type (isotropic biaxial geogrid)	Polymer	Manufactures Nominal Strength* MD / XMD [kN/m]
A	Polypropylene	80 / 80
B	Polypropylene	60 / 60
C	Polypropylene	40 / 40
D	Polypropylene	30 / 30
E	Polyester	60 / 60
F	Polyester	40 / 40
G	Polyester	30 / 30

Molecular State: Highly oriented, semi-cristalline
Macro Structure: Pre-stretched monolithic flat bars welded at right angles
**NOTE:* Short-term strength according to Manufacturer Specification

Table 2. Test data obtained after GRI-GG2 (1987)

Junction	Geogrid						
	A	B	C	D	E	F	G
1	632	441	363	371	1443	985	841
2	646	427	366	386	2056	1014	726
3	439	438	353	380	2251	1064	875
4	549	424	345	370	2060	1013	900
5	641	505	339	373	2103	1061	567
6	608	380	367	390	2134	967	915
7	498	461	376	384	2160	1080	862
8	497	356	364	388	1773	1029	801
9	443	448	353	375	1383	1018	911
10	548	389	383	337	1976	997	788
11	566	397	321	376	1984	856	944
12	525	466	333	403	2027	1017	960
13	374	486	304	366	1401	1073	911
14	547	407	310	371	2107	991	808
15	462	330	310	378	2049	1019	947
16	620	435	376	375	1922	810	886
17	218	443	342	364	1722	758	745
18	519	429	347	339	2112	667	548
19	461	467	345	345	2094	687	599
20	604	371	404	361	1892	515	686
Average	520	425	350	372	1932	931	811
Standard Deviation	104	44	26	17	258	160	128
	20%	10%	7%	4%	13%	17%	16%

All values in [N]

Table 3. Test data obtained after Kupec et al (2004)

Junction	Geogrid						
	A	B	C	D	E	F	G
1	753	644	520	566	2445	1097	1415
2	796	557	439	571	2380	1173	1264
3	1035	633	470	520	2564	1213	1228
4	785	629	460	596	2434	1203	1233
5	579	618	460	530	2315	1334	1168
6	655	579	470	535	2337	1061	1173
7	612	633	505	672	2423	1163	1137
8	774	492	687	601	2456	1087	1163
9	264	622	561	566	2369	1203	1203
10	720	590	480	515	2217	1082	1087
11	655	579	510	621	2423	1026	1324
12	709	622	460	500	2445	1208	1259
13	709	655	439	637	2358	1092	1269
14	644	525	465	485	2619	1087	1289
15	492	514	470	682	2478	1137	1097
16	633	688	490	561	2326	975	-/-
17	547	622	556	571	2272	920	-/-
18	894	655	480	490	2586	819	-/-
19	731	633	500	530	2489	950	-/-
20	709	677	642	525	2489	490	-/-
Average	685	608	503	564	2421	1066	1221
Standard Deviation	156	53	65	57	103	180	88
	23%	9%	13%	10%	4%	17%	7%

All values in [N]

Table 4 Comparison of test results for welded geogrids made from Polypropylene [PP]

		Welded Geogrid [PP]			
		A	B	C	D
Nominal Strength	[kN/m]	80/80	60/60	40/40	30/30
AVG GRI-GG2	[N]	520	425	350	372
AVG Strathclyde	[N]	685	608	503	564
GRI-GG2 / Strathclyde	[%]	76%	70%	70%	66%

Table 5 Comparison of test results for welded geogrids made from Polyester [PET]

		Welded Geogrid [PET]		
		E	F	G
Nominal Strength	[kN/m]	60/60	40/40	30/30
AVG GRI-GG2	[N]	1932	931	811
AVG Strathclyde	[N]	2421	1066	1221
GRI-GG2 / Strathclyde	[%]	80%	87%	66%

5.3 *Index Testing*

The number, size and conditioning of the test samples for both tests were identical. The test procedures were also identical. Thus, all the test specimens were cut and prepared according to BS EN 20139 (1992) and exposed to the test environment of 20ºC and 60% relative humidity at least 24 hours prior to testing. The tensile test machine employed for the testing was capable of reaching loads up to 20kN applied at a constant rate of deformation. A calibrated load cell was attached to an electronic data logger. The load cell was calibrated up to the maximum load expected to be reached during testing, which was 1.5kN.

The only difference between the two test methodologies lay in the clamping arrangements, as shown in Figures 2 and 3. The GRI GG2 (1987) clamp allows shear and torque to develop in junctions which are not in the same plane as the tensile bars. The Strathclyde, Kupec et al (2004), clamp ensures that only shear is applied to such junctions. In order for the Strathclyde clamp to act in this manner, the junction clamp must be customised for each geogrid product.

For the testing, the bottom clamp used was an unmodified high-friction clamp that holds the sample across its full width in the standard manner. The top clamp was modified according to GRI GG-2 (1987) or Kupec et al (2004). A prepared test specimen was inserted into the clamps, the clamps were then closed and secured, and placed into the tensile testing machine. The tests were conducted at a cross head speed of about 50mm/minute. After testing, the specimen was removed from the clamps and examined to determine the mode of failure, Fig. 4.

GRI GG-2 (1987) suggested the testing of at least 10 specimens to determine specimen variation and reproducibility, however, the number of specimens was increased with up to 20 samples tested to account for specimen variation and to check various welding positions.

6 TEST RESULTS

Seven geogrids with welded junctions manufactured with either Polypropylene [PP] or Polyester [PET] and Nominal Strength ranging from 30 to 80kN/m were tested. Their properties are presented in Table 1. Twenty samples for each geogrid product were prepared and tested as described in GRI GG2 (1987). Test data, in form of junction rupture strength, for each geogrid are given in Table 2, together with the standard deviations and average values.

Twenty samples for each geogrid product were prepared and tested, as detailed in Kupec et al (2004). Test data for each junction are given in Table 3, together with the standard deviations and average values.

Tables 4 and 5 shows the average test results from the seven geogrids obtained by the two different test methods. As can be seen from the test data the junction strengths obtained from the GRI GG2 (1987) test method is consistently lower than the Strathclyde test method, i.e. samples tested under shear forces only exhibited significantly higher strengths than those tested with a combination of shear and torque forces.

7 CONCLUSIONS

- Geogrids with different directional properties, manufactured by various methods were identified and their differences in tensile stiffness and strength were discussed.
- Different junction types were identified and classified in to two broad categories, i.e. junctions that possess adequate unconfined junction strength to transfer stresses from one set

of bars to another and those that require significant confined pressures before they are able to transfer stresses.

- For different types of applications and operational environments, it was shown that the uniaxial or biaxial junction behaviour is dominated the geogrid ‘in-soil’ behaviour.
- It was found that at low strains under either uniaxial or biaxial load/strain conditions only shear forces are likely to develop at the junctions.
- For large strains under uniaxial or highly anisotropic conditions shear and torque forces develop in the junctions.
- It is suggested that the established GRI GG-2 (1987) test method, which generates shear and torque forces on a junction, is applicable to geogrids with integral junctions and welded junctions when large strains are mobilised.
- It is suggested that the test method developed at the University of Strathclyde, Kupec at al (2004), is applicable to low uniaxial strains and any isotropic biaxial loading conditions for both integral and welded junctions.
- It is suggested that the operational performance of geogrids with heat-bonded and woven junctions is dependent on the applied confining pressures. Therefore, ‘in-soil’ testing at operational confining pressures instead of unconfined ‘in-isolation’ testing is recommended for these types of geogrids.
- It is emphasised that the junction strength test methods presented were developed as Index (quality control) tests only and are not suitable as Performance (design) test methods.
- It is important to use an appropriate Index (quality control) test method. The test method to be used may vary with the geogrid type.
- Although, an attempt has been made in this paper to relate test results obtained from Index (quality control) testing to operational conditions, i.e. plane-strain or isotropic strain conditions at SLS and ULS conditions, care has to be taken to ensure that an appropriate interpretation of such test data is undertaken.

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