MODELLING GEOGRID BEHAVIOUR: THE INFLUENCE OF JUNCTIONS ON THE BEHAVIOUR OF VARIOUS TYPES OF GEOGRIDS

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Abstract: This paper discusses the influence of the behaviour of different types of junctions on the performance of geogrids when tested in air and operationally when confined in soil. To date in air strength testing of junctions has been specifically aimed at determining the manufacturing consistency of geogrid products rather than determining their operational performance. However, sometimes in air test results on junctions have been combined with data from separate tests on the structural members to infer the in soil behaviour of geogrids.

This paper describes the different junction types and the test methods employed to determine junction strength when unconfined and confined. It then relates the junction behaviour to the geogrid behaviour in air and when confined in soil at working, Serviceability Limit State and Ultimate Limit State conditions. It includes analysis of laboratory test data on junction strength and discusses the behaviour and testing of geogrids under operational conditions, including uniaxial and biaxial in-plane loading conditions.

Keywords: geogrid, quality control, index testing, long-term behaviour.

INTRODUCTION

Geogrids are produced in a variety of geometrical forms using a wide range of polymeric materials and numerous manufacturing techniques. To date, two classes of geogrid reinforcements have been 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 different behaviours and are generally employed in different applications.

Geogrids comprise different types of structural members, including bars, fibres and filaments, connected by 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, fibres or filaments comprising their main structural members. Thus, for most in-plane tensile loading conditions, whether in air or when confined in soil, only axial forces are applied to the material forming the junctions. For geogrids with heat-bonded or welded junctions, the junctions are usually offset from the central axis of the main structural members. Thus, for most in-plane tensile loading conditions, shear forces are applied to the material forming the junctions. As a result there can be a degree of rotation of the main structural members entering the junctions, particularly in soil and at large deformations. This can result in tearing of the junctions away from one set of the structural members, Ziegler & Timmers (2003) and Ziegler & Timmers (2004). Therefore, in air and at large deformations in soil, the junctions of geogrids with heat bonded or welded junctions may be subject to both shear and torsion.

In this paper, the differences in the nature of geogrids manufactured by different processes are identified. The operational behaviours of these geogrids are then discussed. Details are given of two Index test methods for in air junction strength testing. Test results are presented, compared and related to the operational behaviours of junctions. The influence of the junctions on the overall behaviour of different types of geogrids under uniaxial and biaxial, in-plane loading conditions at working, Serviceability Limit State and Ultimate Limit State conditions are discussed.

GEOGRID TYPES

Geogrids are manufactured from a wide range of polymers. These are extruded into bars, fibres or filaments that are drawn to alter their physical and mechanical properties. The process of drawing, performed either at room or elevated temperature, changes the molecular alignment from amorph, (where the molecules are randomly oriented), to semi-crystalline, (where the majority of molecules are aligned in the direction of the principal stress during drawing). As a result, the load carrying capacity, (both stiffness and strength), of the drawn polymer is increased. In general, the higher the degree of crystalinity, the stiffer and stronger the polymer becomes, however, with increasing crystalinity so brittleness increases. Thus compromises have to be achieved between stiffness / strength and brittleness, Seymour (1975), ACSE (1984), Seymour (1991) and Voskamp & van Vielt (2001).

To date, geogrids have been divided into uniaxial and biaxial products, Figure 1. However, it is known that geogrids which can develop tensile stiffness and strength in three or more directions are now being developed.

Uniaxial geogrids

Uniaxial geogrids usually exhibit a high stiffness and strength in one particular direction and a very low to negligible stiffness and strength in the other direction. The main functions of the secondary cross-members and

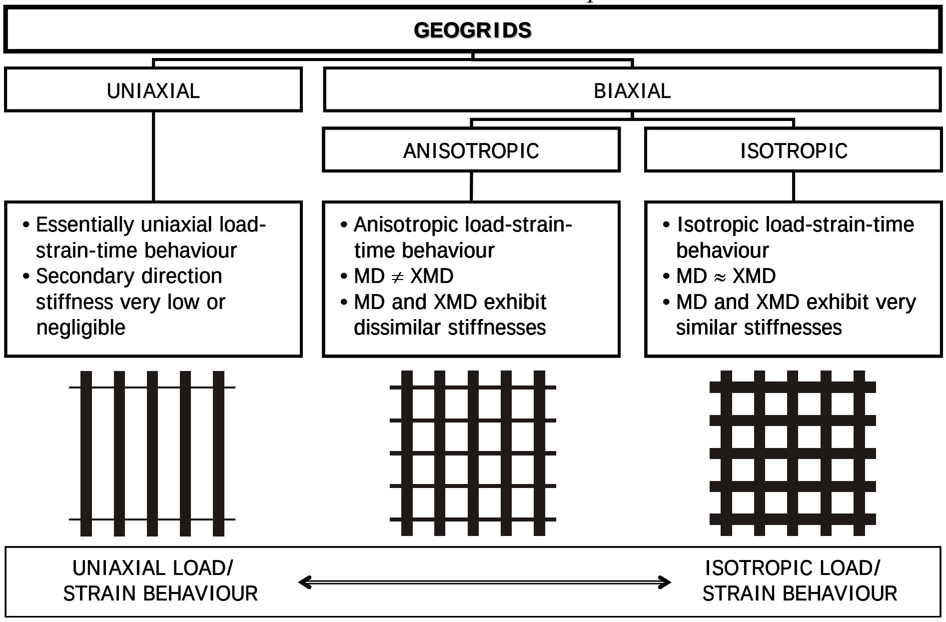

Figure 1 Geogrid types

junctions are to provide geometrical stability during transport and installation, and when confined in soil to provide the possibility of interlock with the soil particles. Such uniaxial geogrids are intended for use in plane strain applications.

Biaxial geogrids

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 may 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 in orthogonal directions. 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.

JUNCTION TYPES

The junction types now in use include entangled fibres or filaments; heat, chemical, laser or microwave bonded bars; welded bars and integral junctions formed during the drawing of punched sheets, Figure 2. All these types of junctions provide some degree of geometrical stability during transport and installation.

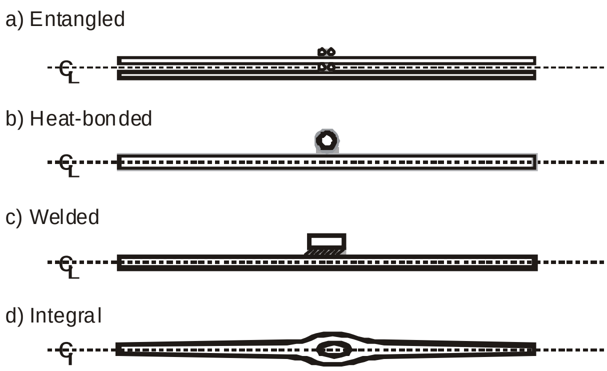

Figure 2 Junction types

In air testing indicates that two broad categories of geogrids can be identified, viz. those with junctions capable of load transfer and those with junctions that cannot transfer loads, Kupec & McGown (2004) and McGown & Kupec (2004). However, geogrids formed with junctions that cannot transfer loads in air may develop sufficient junction strength to transfer loads when they are subject to normal confining stresses in soil.

Geogrids with junctions capable of load transfer in air and when confined in soil

Most geogrids with junctions capable of load transfer in air and when confined in soil are produced with bars and either integral junctions or welded junctions. The main aims of these types of junction are to transfer loads within the grid and to maintain their geometrical shape during transport and installation.

Integral junctions

Integral junctions are commonly produced from a polymeric sheet which is first punched and then stretched in one direction, usually the machine direction [MD], to form a uniaxial geogrid, or in two directions, the machine direction [MD] and the cross machine direction [XMD], to form a biaxial geogrid, Mercer (1987). The salient feature of these geogrids is the variation of their molecular alignments along the lengths of their MD and XMD directions. The molecular alignment is highest (crystalline to semi-crystalline) in the stretched bars and reduces towards the junctions. The junctions are largely in an amorph state and are therefore more prone to exhibit time dependent deformations (creep) than the bars, Yogarajah (1992).

Welded junctions

Geogrids with welded junctions are produced in two distinctly different manufacturing processes, viz. the bars are formed first and then joined together by various methods to form the geogrid. The bars are commonly formed from extruded polymers. They may be stretched at the time of extrusion and subsequently form bars with highly aligned molecular orientation. The formation of the junctions may involve heat or chemical bonding, laser, microwave or other welding processes. The main aim is to strongly bond the two sets of bars together in the least intrusive manner, since the junction formation process may influence the load-strain properties of the bars by locally reducing the degree of crystalinity in the bars.

Geogrids with junctions capable of load transfer only when confined in soil

Several forms of geogrids do not possess junctions with significant load transfer capability when tested in air. The main purpose of these junctions is to maintain the grid geometry during transport and installation. The manufacturing process often involves the production of bars, fibres or filaments that are chemically or physically bonded to form the grid shape. Often a protective coating is applied later. Although the junction is not capable of transferring significant loads between the cross-members when in air, such junctions may develop load transfer capability when confined in soil at medium to high confining stresses.

JUNCTION STRENGTH TESTING METHODS

The commonly recognised quality control (Index) test methodologies for junction strength are those reported by GRI-GG2 (1987), Montanelli & Rimoldi (1994) and the Tex-621-J (2002). These were developed for geogrids with integral junctions. For such geogrids the axis of the junctions is essentially in the same plane as the central axis of the bars. Thus the applied in-plane loading regime used in these tests develops only tensile loads in the junctions. Further, it should be noted that these test methods were developed for and intended only for use as quality control tests in order to assess the consistency of manufacturing processes.

More recently another test method has been developed suitable for a wider product range, Kupec *et al.* (2004) and Kupec (2004). Once again it should be noted that this method is intended only for quality control purposes and represents the unconfined in air rather than confined in-soil (operational) strength of junctions.

Kupec (2004) and Kupec *et al.* (2004) reported testing geogrids with integral and welded junctions, according to both GRI GG2 (1987) and their method. They suggested that the main advantage of their test method was that it prevented out of plane rotation (torsion) developing in the junctions.

An assessment of index junction strength test methods

The number, size and conditioning of the test samples for both the GRI GG2 (1987) method and the Kupec (2004) and Kupec *et al.* (2004) test method were identical. 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 for at least 24 hours prior to testing. The tensile test machine employed for the testing was capable of reaching loads up to 20kN. The test specimens were tested at a constant rate of deformation of 50 mm/min. A load cell was attached to an electronic data logger and was calibrated up to the maximum load expected to be reached during testing.

The only significant difference between the test methodologies lay in the clamping arrangements, as shown in Figures 3 and 4. The GRI GG2 (1987) clamp allows shear and torsion to develop in junctions that are not in the same plane as the main structural members. The clamp set up for the Kupec (2004) method ensures that only shear is applied to such junctions. The bottom clamp used was an unmodified high-friction clamp that holds the sample across its full width in the standard manner and the top clamp was modified according to GRI GG-2 (1987).

For both types of testing, the specimen was removed from the clamps and examined to determine their mode of failure.

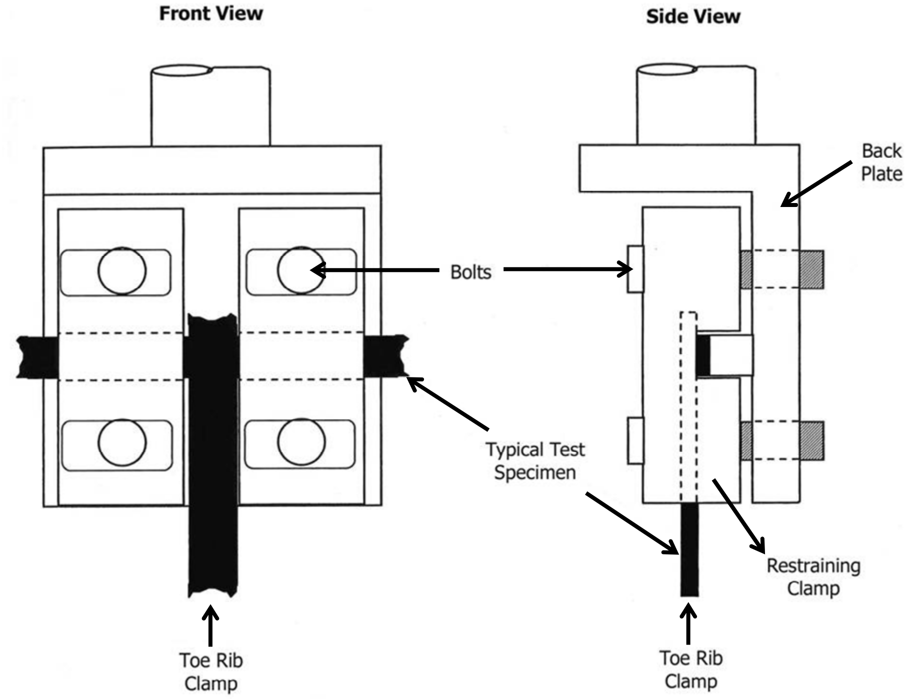

Figure 3 GRI GG2 (1987) clamp set up

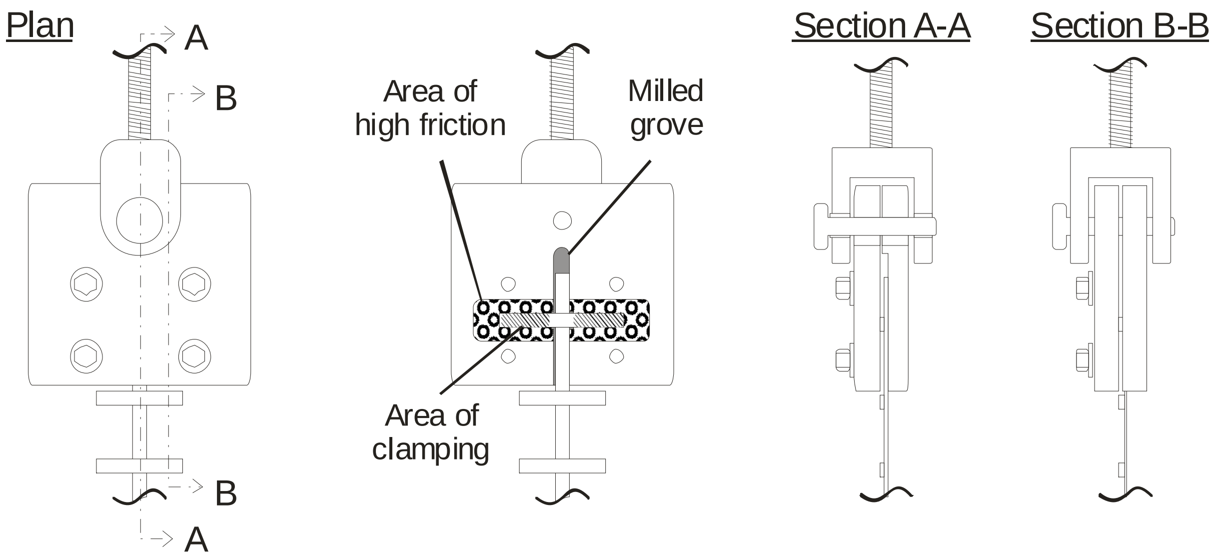

Figure 4 Kupec (2004) and Kupec *et al.* (2004) clamp set up

The two junction clamping arrangements provided the same failure loads and deformations for integral junctions but were found to develop significant differences in failure loads and deformations for welded out of plane junctions. This was attributed to the prevention of out of plane rotation of the welded junctions during loading and emphasised the need to match operational behaviour to test conditions, even for Index Junction Testing.

An assessment of performance junction strength testing

To date, no performance junction strength test methods are known to have been developed which reasonably replicate the behaviour of geogrid junctions under confined in soil and subject to either sustained or repeated loading regimes. Pull out testing has been employed to determine overall soil-geogrid interaction properties and some special pull out tests have been performed on short strips of geogrids to examine the behaviour of junctions. These have involved dragging various numbers of junctions through different types of soil, however, these tests often involve significantly higher geogrid deformations than under working or Serviceability Limit State conditions. Thus, this type of testing does not always provide data which is representative of the operational performance of geogrid junctions at low to moderate deformation levels. For this reason the data from pull out tests related to junction behaviour must be very carefully interpreted.

GEOGRID STRENGTH TESTING METHODS

Mathematical modelling of the load-strain / strength / stiffness properties of geogrids products based on test data from junction strength tests combined with data from separate tests on the structural members, is rarely appropriate. This is due to the complex stress conditions that can be generated in the junctions under various loading regimes and due to the local changes that can be developed in the structural members at or close to the junctions by the junction forming processes employed to manufacture the geogrid. Thus, it is almost always necessary to undertake testing of geogrid products in order to obtain representative data on their load-strain / strength / stiffness behaviour. Further, as is the case with most geosynthetic products, more than one test method will require to be employed for quality control purposes and to evaluate the ability of geogrid products to withstand the diverse range of stresses and strains imposed under different operational conditions, Myles (1987). Therefore, specifiers and end users of geogrid products will be required to undertake a range of quality control (Index) tests and Performance tests appropriate to the operational conditions.

Index geogrid strength test methods

McGown and Kupec (2004) reported that Index strength tests aim to determine only the short term properties of geogrid products for quality control purposes. They stated that uniaxial CRS testing of geogrids for quality control purposes is now well established with numerous National and International Standards in existence, including BS 6906-Part 1 (1987), ISO 10319 (1993) and ASTM D 4595-86 (1994). However, they emphasised that the size and shape of the test specimens used was very important. The choice of the number of junctions and structural members in the test specimens had to be sufficient to be representative of the product and the aspect ratio of the test specimen had to be sufficient to ensure uniform stress conditions during testing. In suggesting this they were confirming the recommendations made by Myles (1987) for geotextiles, who explained the need to use wide width geotextile test specimens with an aspect ratio of at least 2:1, (width to height).

For uniaxial geogrids, these Index tests need only be carried out in the direction of their load carrying capacity. For both anisotropic and isotropic biaxial geogrids, the Index tests need to be carried out in the two orthogonal directions of their load carrying capacity.

Tests carried out in the above manner, will provide a full quality control assessment of the overall product, including the junctions and structural members, as required by specifiers and end users and so obviate the need for separate testing of junctions and structural members by other than manufacturers.

Performance geogrid strength test methods

McGown and Kupec (2004) also reported on the aims of Performance testing of geogrids. They confirmed that for uniaxial geogrid products, uniaxial testing with loading regimes appropriate to the operational conditions, would provide representative data on their load-strain / strength behaviour. Once again they emphasised the need to carefully select the size and shape of the test specimens, as discussed above for Index testing.

For biaxial geogrid products, McGown and Kupec (2004), suggested that combining test data from uniaxial tests in the orthogonal directions of the load carrying capacity of the geogrids, would not always provide an appropriate representation of their load-strain / strength behaviour. Rather they suggested that for biaxial geogrids with integral junctions and for others with a significant junction load transfer capability, biaxial testing using loading regimes appropriate to operational conditions, would be required. Once again they clearly identified the need to carefully select the size and shape of the test specimens.

The need to carry out Performance tests on geogrids in air or when confined in soil is another important consideration and the influence of confinement stresses in soil on the behaviour of the junctions is critical to this. Another factor is the level of operational deformations / strains imposed. For geogrids formed with junctions whose strength is not dependent on in soil confinement stresses and for low to moderate operational deformation / strain levels, in air testing is often representative. However, for geogrids formed with junctions greatly influenced by in soil confining stresses and for high deformation / strain levels, in soil testing will be required.

DISCUSSION & CONCLUSIONS

Geogrids with different directional properties, manufactured by various methods were identified and their differences in load-strain and strength were discussed. Different junction types were identified and classified in to two broad categories, i.e. junctions that possess significant unconfined (in air) junction strength for the transfer of stresses from one set of structural members 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 can dominate geogrid in-soil behaviour. It was found that at low strains for either uniaxial or biaxial loading regimes only direct and / or shear forces are likely to develop at the junctions. For large strains under uniaxial or highly anisotropic conditions direct, shear and torsion forces may develop in the junctions.

It is suggested that the established GRI GG-2 (1987) test method, which can generate shear and torsion forces in some types of junctions, is applicable only to geogrids formed with integral junctions. It is suggested that the test method developed by Kupec *et al*. (2004) is applicable to both integral and welded junctions. However, the behaviour of heat-bonded and other forms of junctions is dependent on the application of a confining pressure, therefore, in soil testing at operational confining pressures instead of unconfined in air testing is recommended for these types of junctions. It is emphasised that the junction strength test methods presented are quality control (Index) tests and are not suitable as Performance junction test methods.

It was suggested that although attempts have been made in the past to relate test data obtained from Index testing to operational conditions, the outcomes are rarely appropriate for either product comparison, design or specification. Therefore, recommendations have been made for in air and in soil performance testing of representative samples of geogrid products in order to assess their load-strain / strength / stiffness properties for design purposes.

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