

## **Index and performance testing a new geogrid made of highly oriented straps.**

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### *1. Abstract*

A new geogrid made of separate straps, welded together at the connections using a laser welding technique has been developed after years of intensive research. The newly developed and patented welding system is described in this paper. It allows the highly stretched and oriented straps to be welded together without losing the orientation of the molecules in the welded area. This is very important because otherwise a change of material properties will occur which will influence the long term strength and creep of the material. Further it results in very efficient use of material and therefore in a cost-effective material.

The new geogrid combines the strong properties of stiff grids with the advantages of flexible geogrids and can be made of various polymers. In this way the most suited polymer can be selected to fulfil the required properties in the application. Further the welding technique results in rigid connections between the straps. PET straps are used for long term applications as slope reinforcement; PP straps for applications with short term strength requirements such as road reinforcement. The results of various index tests and long-term performance tests like creep, mechanical damage and pull-out are shown. The long-term tensile strength ( $T_{al}$ ) is calculated using the method described in FHWA-SA-96-071.

### *2. Introduction*

Currently two groups of geogrids are available:

- stiff geogrids
- flexible geogrids.

The stiff geogrids are mostly made of extruded sheets that are stretched after holes have been punched into them. They are available as uniaxial geogrids, mostly

made of High Density Polyethylene (HDPE) or as biaxial geogrids, mostly made of Polypropylene (PP). The strength of the uniaxial geogrids is generally between 35 and 150 kN/m (or 2400 – 10300 lb./ft.) in machine direction. They have traditionally a width of 1.0 to 1.3 m. The biaxial geogrids are mainly available with strengths between 20 and 40 kN/m (1370 – 2740 lb./ft.) in machine and cross machine direction and have mostly a width of 4m. The connection strength between the bars or the so-called junction strength is very high because the material is monolithic. The material is oriented between the nodes, in the nodes is a zone of less oriented material. The polymer, which is used, has a relatively high creep rate, which results in more material, used to reach a comparable strength level (the comparison is made to other geogrids and on the basis of strength levels).

The flexible geogrids are mostly made of woven Polyester (PET) yarns, which are woven in a grid structure. The grid is coated with a PVC or Acrylic coating. The yarns are highly oriented and have good creep properties. The coating gives protection to the yarns against mechanical damage and ultra violet attack.

The geogrids can be made to widths of 5 m and their flexibility eases the installation but it can also be a disadvantage. The junctions between the length and the crossbars have a lower strength compared with the stiff geogrids. Of course the required level of junction strength should be evaluated in pull out tests and cannot simply be set as equal to the strength of the length bar. The specified junction strength in actual projects has caused many arguments as only stiff geogrids can theoretically reach the level of 100%. It is still often used as an argument to make the specification exclusive for certain products. At the same time advantages of flexible geogrids have been used in specifications to get a competitive edge for those materials.

Colbond Geosynthetics (formerly known as Akzo Nobel Geosynthetics) has been involved in the development and subsequent production of soil reinforcement materials like Stablenka reinforcing fabrics and Fortrac Geogrids since 1974. Many papers have been published about the testing done on these materials. For example the 14 years of creep testing on PET yarn, the extensive research on hydrolysis effects and many case studies. Especially in the early years we have been involved in the development of the calculation methods for base reinforcement and slope reinforcement applications. In 1985 we published a method to establish the long-term design strength of soil reinforcement materials using partial reduction factors (Voskamp, 1985)<sup>ii</sup>. We have also published test results on material that was reclaimed from the ground after the end of the service life (Troost e.a., 1994)<sup>iii</sup>.

After the introduction of flexible geogrids in the market with Fortrac in 1986 as the first, it became clear that these products did not have an exclusive production technique. They can be reproduced as no patents on the product or manufacturing system could be obtained. This has indeed happened in the years after and now many flexible geogrids with nearly identical properties are available and have helped to grow the soil reinforcement market.

In the early 1990's, it was decided in Colbond Geosynthetics that we should develop a completely new geogrid made with an advanced technology. This technology should be unique and the system should be patented. The geogrid should combine the strong properties of both existing types of geogrids.

The result of this decision was a, as we now know, 7-year development program in which the new geogrid was developed and tested.

### 3. *Development of the new geogrid*

#### 3.1 *Objectives of the development*

The objectives of the development program were to develop a geogrid with:

- creep properties of PET
- high rupture strength in relation to the material use
- rigid connections
- ability to produce 5 m wide rolls
- good durability
- competitive market price
- possibility to be patented

The program started in 1993.

The first logical conclusion was that if we did not want to make a grid from yarns and also not from extruded sheets, it should be made from strips. Strips have the advantage of stiffness and have a better resistance against chemical influences as the outside area is small compared to a bundle of yarns. (The speed of many chemical processes is related to the outside surface area of the element and therefore a strip is a better shape of material than a bundle of multi-filament yarns). Further the orientation of the molecules as a result of the stretching is not interrupted at the junctions, provided that the junction itself does not disturb the orientation.

Polymer straps are existing products, mainly used for strapping around carton boxes or for other applications in the packaging business. The polymer most often used is PP. While straps can be made from other polymers, they are not often used. However it is possible to make straps of PET that can be oriented to high levels.

#### 3.2 *Connection systems*

The connection between the straps can be made in various ways:

- gluing
- heat bonding
- friction heating
- ultra sonic welding
- micro wave welding
- laser welding

Connections by means of gluing are not desirable, as the connection does not have a high rigidity and as the method is expensive in material use.

Heat bonding is an existing method but it damages a thick layer of the straps. The effect of the orientation is lost in this layer and the long-term behavior is questionable. This means that when such a method is used, the straps must be made with an extra thickness. The heat can be introduced from one side, so the extra thickness in the other strap can be limited but still a lot of extra material is needed. The quality control of such a connection is also a difficult point as when the bonding temperature is too high, the thickness of the layer in which the disorientation of the second strap takes place is also increased and the long-term performance of the strap is decreased. Friction heating is a method where heat is developed in the interface between the two straps by means of movement of the two straps over each other. A commercial application of the method for the connection of straps was developed around fifteen years ago, but after some years the production was stopped.

Ultra sonic welding is a method that is often used for the connection of layers of geosynthetic materials in geocomposites. Control of the thickness of the heated interface is difficult, so also with this method extra material is required and quality control is difficult. Microwave welding and laser welding techniques have the opportunity to control the thickness of the heated area continuously and to limit the thickness of this area to a very thin layer.

Table 1. Effects of welding system on material properties of straps

	Rigidity of connection	Material use	Thickness of interface layer	Effects on orientation of length straps	Quality control
Gluing	-	o	+	+	-
Heat bonding	o	--	--	--	--
Friction heating	+	-	-	o	o
Ultra sonic	+	-	-	-	-
Microwave	+	+	++	++	++
Laser welding	+	++	++	++	++

+ = Positive or no negative influence

- = Negative influence

o = No major influence

Based on the know-how in 1993, it was decided to start with research and development of the microwave welding system.

### 3.3 *Microwave welding system*

The principle of the system is that a layer of high carbon content is present at the interface of the straps at the location of the connection. The layer with high carbon content absorbs the energy and becomes hot, when the strips are brought in the influence space of the microwave. This special layer can be produced as part of a bicomponent strap.

Laboratory tests have been executed and prototypes were made. Patents for this system have been applied for and are already granted in many countries.

With the scaling up of this system to repetitive welding, it became clear that the system was vulnerable for contamination and in fact required material tolerances that were hard to achieve in normal practice. Also the reliability of the system could not be assured. As a result the development of this system was put on hold and a re-evaluation of the other systems including the latest commercial developments on materials and equipment was made.

### 3.4 *Laser welding system*

In 1995 it was decided to concentrate the developments on the laser welding technique.

With this technique it was possible to fulfil all requirements set for the new geogrid. It is not an existing technique and all elements had to be developed. After successful completion of the tests for the performance of the prototype, scaling up was done to test repetitive welding etc.

This was followed by pilot testing of production equipment, which was especially designed for the production of this geogrid. A complete new design for the production equipment had to be made, with the transfer of the weft straps, fixation of the connections and development of the welding unit as most difficult portion.

At the same time extensive testing of the geogrid material was done, on single straps, on double straps and on 20 cm wide samples of the product.

This all has led to the introduction of the new geogrid in the geosynthetic market at the end of 1999.

### 3.5 *Description of the new geogrid*

The new geogrid is made from polymer straps, connected at the junctions by means of a laser welding system. Two groups of geogrids are available:

- uniaxial geogrids, made of PET straps
- biaxial geogrids, made of PP straps.

Both geogrids are made in rolls of 5 m width and 100 m length.

The PET geogrid, indicated with the description PRO, has a strength range of 40, 60, 90, 120 and 180 kN/m in machine direction, while the PP geogrid, indicated with the description MAX, has equal strengths in both directions and is available in 20, 30 and 40 kN/m.

The geogrids are made of black straps in machine direction and have double transparent weft straps. One strap above and one strap below the length straps, at every connection two transparent straps. This is done to increase the bearing resistance of the geogrid in the ground. The laser light passes the transparent strap and heats a very small layer of the black strap. It is very important that the heated layer is very thin to prevent distortion of the stretched molecules in the highly oriented straps. The polymer material is mixed in this very thin interface layer and in this way forms the connection. With the laser technique it is possible to control the energy which is absorbed by the black strap through variations in light intensity and the welding speed. An example of the microscopic thin interface layer is given in Figure 1, where a photograph is shown of such an interface layer.

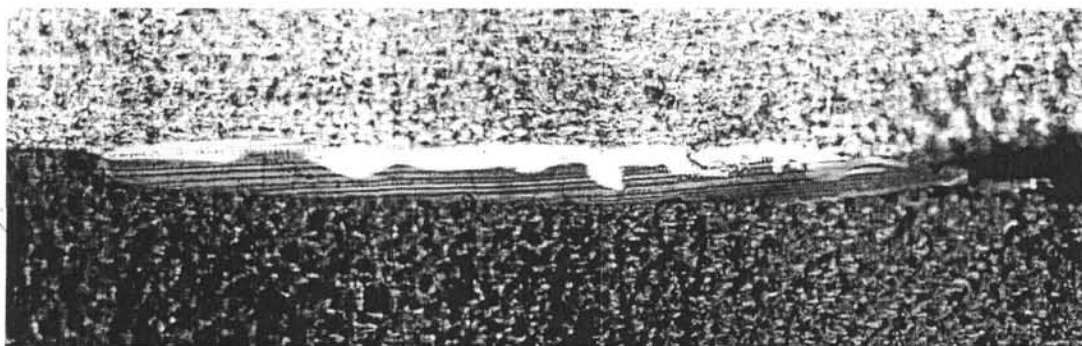


Figure 1. Cross section of a welded area

This welding technique has resulted in very low losses in tensile strength of a welded strap compared with a virgin strap. Typically these losses are for PET material in the range of 5 to 10%. The result of the long term testing has proved that the orientation of the strap material is not influenced. Because the strap material has a better stress-rupture behavior than yarns, the long-term rupture strength is also at a higher level than yarns.

The geogrid is made of straps that are brought into the machine from a creel. The weft straps are put on top of and under the length strap and connected by means of the laser-welded system. Then the geogrid is advanced further along the machine direction and automatically checked for quality before it is wound onto a roll.

#### 4. *Testing*

During the development of the geogrid, many tests have been done to analyze the effects of decisions in the development. Many tests have been executed to determine the properties of the geogrid.

- tensile strength tests
- creep rupture tests
- creep strain tests
- accelerated creep tests
- mechanical damage tests
- UV tests
- weathering tests
- hydrolysis tests
- pull-out tests
- direct shear tests

The results of the tests are shown.

The test results are necessary to determine the various Reduction Factors which have to be used to determine the Long Term Tensile Strength ( $T_{all}$ ).

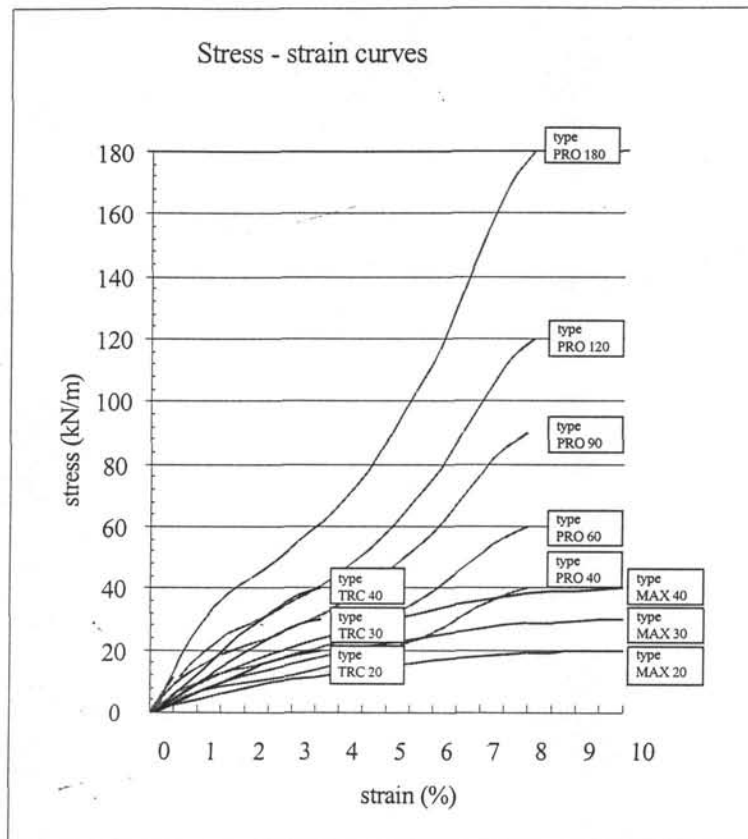
$$T_{all} = \frac{T_{ult}}{RF} \quad \text{with} \quad RF = RF_{CR} \times RF_{ID} \times RF_D \quad (\text{AASHTO, 1997})$$

- $T_{all}$  = long term geogrid tensile strength, (kN/m)
- $T_{ult}$  = ultimate geogrid tensile strength, based on MARV, (kN/m)
- $RF_{CR}$  = creep reduction factor, or ratio of  $T_{ult}$  to creep limiting strength
- $RF_{ID}$  = installation damage reduction factor
- $RF_D$  = durability reduction factor for chemical and biological degradation

The Reduction Factors, which are applicable for this grid, will be determined from the results of the various tests.

#### 4.1 Tensile strength tests

Tensile strength tests have been performed, in accordance with EN 10139 and ASTM 4545. The stress-strain curves are shown in Graph 1. Here the quality control values for the material are shown. The quality control values are defined as a 95% confidence limit value, characteristic strength or as the Minimum Average Roll Value (MARV) as defined by ASTM D 4759. These values are guaranteed material properties. In Graph 1 the stress strain curves for all types are given with the PP types indicated as type MAX... and the PET types indicated as type PRO....



Graph 1. MARV stress-strain curves

#### 4.2 Creep-strain testing

To determine the serviceability state tensile load  $T_w$ , it is necessary to know what the strain is during the lifetime of a structure. AASHTO section 5.8.7.2. requires the calculation of  $T_w$ , the tension level at which the total strain is not expected to exceed 5% within the design lifetime. The strain levels are derived from creep tests in accordance with ASTM 5262-92. The test time should be at least 10000 hrs. and executed at various load levels. Creep tests have been executed on straps and on geogrid samples with representative width (in accordance with EN ISO 13431). Further time temperature superposition techniques have been used to obtain additional supporting data. The stepped isothermal method (SIM) as proposed by Thornton, 1997<sup>IV</sup>, 1998<sup>V</sup>, has been used. The tension level at which the total strain is not expected to exceed 5% within the design life is 44.4% of the MARV tensile strength.

#### 4.3 Creep-rupture tests

Creep rupture tests are executed to determine the creep-rupture strength of the geogrid. This is the rupture strength of the material after a certain loading time. AASHTO section 5.8.7.2 requires this value to be used as  $T_1$  in the limit state design.



Therefore  $RF_{CR} = 1.46$  can be taken.

#### 4.4 Mechanical Damage tests

AASHTO (1997) refers to FHWA-SA-96-072<sup>VIII</sup> for the determination of the sensitivity to installation damage. In this document site tests are described, similar to the method described by Watts and Brady, 1990<sup>IX</sup>. The type of standard fills is described. The ratio of the initial reinforcement strength to the strength of the retrieved samples defines the  $RF_{ID}$ . The  $RD_{ID}$  for fills of other gradation may be interpolated by plotting against  $d_{50}$  for the respective fills.

TRI/Environmental, Inc. in Austin has executed the tests. The results are:

Machine direction	type PRO 40	type PRO 60	type PRO 90	type PRO 120	type PRO 180
Silty loam < 1mm	1.04	1.03	1.03	1.05	1.07
Sandy gravel < 20 mm	1.11	1.11	1.12	1.17	1.21
Course gravel < 75 mm	1.31	1.26	1.21	1.30	1.39

Machine direction	type MAX 20	type MAX 30	type MAX 40
Sandy gravel < 20 mm	1.02	1.02	1.02
Course gravel < 75 mm	1.01	1.02	1.03

Cross Machine direction	type MAX 20	type MAX 30	type MAX 40
Sandy gravel < 20 mm	1.02	1.03	1.04
Course gravel < 75 mm	1.05	1.05	1.05

Table 2. Mechanical Damage Test results

Interpolations between the various test results have been made in accordance with the FHWA documents procedure to complete the range.

#### 4.5 Durability tests

The PET geogrids have a molecular weight  $M_n$  of 30.800, measured to ASTM D 4603. The Carboxyl end group count is 12.7, measured in accordance with GRI test method GG7. The material does not contain post-consumer recycled material. The allowed default value for  $RF_D$  according to AASHTO (1997) would then be 1.15 for soils with  $5 < pH < 8$  and 1.3 for soils with  $3 < pH < 5$  or  $8 < pH < 9$ .

Hydrolysis tests have been executed in accordance with the requirements of prEN 13251 and ISO CR 13434. They require hydrolysis testing at  $95^\circ C$ ,  $pH=7$  for 28 days. The requirement is that the retained strength is minimal 50%. For the new geogrid a value of 64% was determined. This means that the retained value is much

better than is expected for the use of the default value. AASHTO (1997) requires that the geogrid has more than 70% retained strength after 500 hrs in a weatherometer in accordance with ASTM D 4355 and ENV 12224. ISO/TR 13434 requires even 80% retained strength. Geogrid type PRO had as retained strength 99% in the weathering test and a retained strength of 98.3% in the UV test. The RF for these conditions is 1.0 as the test results are within the accuracy limits of the tests, theoretically the value could be 1.02.

#### 4.6 *Pull-out tests*

Pull-out tests have been executed on the geogrid. The tests have been done in accordance with the GRI GG5 method. The values found for the pull out resistance factor are between 0.8 and 1.0 for a typical soil, concrete sand, 0.1 - 5 mm. The default value,  $C_i$ , for PET geogrids is 0.8 and for the PP geogrids 1.0.

A factor  $F_{s-po}$  is applied in the design. The calculated anchor length in the design is multiplied with this factor of safety.  $F_{s-po} = 1.5$ .

#### 4.7 *Direct shear tests*

TRI/Environmental Inc.<sup>X</sup> has performed direct shear tests to determine the coefficient of direct sliding on the geogrids. The tests have been executed according to ASTM D 5321. The result for PET grids in concrete sand, 0.1 - 5 mm, is  $C_{DS} = 0.87$  and for PP grids in sandy gravel, 0.1 - 15 mm, is  $C_{DS} = 0.93$ .

### 5. *Reduction factors.*

The method to determine the LTDS of a geogrid was given in paragraph 4.0.  
 $RF_{CR} = 1.46$   
 $RF_{ID} = 1.03 \dots 1.39$ , depending on the fill and the type of geogrid  
 $RF_D = 1.02$

This gives a total RF of: 1.53 .... 2,06; or 1.84.....2.47 in case an extrapolation factor of 1.2 is applied.

AASHTO (1997) requires as minimum default values:  
 $RF_{CR} = 1.46$  (eventually in combination with an extrapolation factor of 1.2)  
 $RF_{ID} = \text{minimal } 1.1$   
 $RF_D = 1.15$  or 1.3 depending on the pH value of the soil.

The total RF should not be less than 3.0 for permanent structures and 2.0 for temporary structures. The values, which are used in designs according to BS 8006, are:

(The reduction factor is called  $f_m$ , the categories and the calculation method for the long-term design strength are the same).

$f_{m11}$	= the partial material factor for manufacturing accuracy	= 1.0
$f_{m121}$	= the partial material factor for assessment of available data	= 1.1
$f_{m122}$	= partial material factor for assessment of statistical analysis	= 1.1
$f_{m21}$	= partial material factor for installation damage	= 1.03...1.39
$f_{m22}$	= partial material factor for durability	= 1.0 ...1.15
$T_{all}$	= rupture strength for a certain design life, in case of 120 years	= $0.68 * T_{uts}$

The comparable total Reduction Factor according to the BS 8006 is 1.83...2.47. These values are about equal to the RF values calculated in accordance with the AASHTO method. It should be noted that the additional RF for extrapolation, or the  $f_{m121}$  and  $f_{m122}$  for assessment of the available data and statistical analysis would become 1.0 in the near future.

## 6. Conclusion.

The result of tests of the new geogrid shows that the grid has a very efficient use of the material components. Strength losses in the connection system are very small. The creep results give higher values than the rupture values known for PET yarns. This is caused by the use of highly oriented straps rather than yarns. The mechanical damage reduction factor are comparable to those of other geogrids, the values in combination with sharp edged fill material are very good.

The total reduction factor used to determine the Long Term Tensile Strength according to the methods described in FHWA-SA-96-071 and 072 is comparable to the total material factor  $f_m$  used in the calculation of the Long Term Design Strength according to the BS 8006.

## 7. References:

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<sup>VI</sup> Greenwood, J. H., ERA Technology Ltd, UK. Creep and stress-rupture assessment of Enkagrid, project no. 04462106, 1999.

<sup>VII</sup> Elias, V. and Christopher, B.R., Mechanically Stabilized Earth Walls and Reinforced Soil Slopes, Design & Construction Guidelines, FHWA-SA-96-071, U.S. Department of Transportation, Federal highway Administration, Washington, D.C., August 1997, p. 371

<sup>VIII</sup> Elias, V. Corrosion/Degradation of Soil Reinforcements for Mechanically Stabilized Earth Walls and Reinforced Soil Slopes, FHWA-SA-96-072, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. August 1997, p. 105

<sup>IX</sup> Watts, G.R.A. and Brady, K.C., Site Damage Trial on Geotextiles, 4<sup>th</sup> International Conference on geotextiles and Geomembranes and Related Products, The Hague, The Netherlands, 1990, pp. 603-608

<sup>X</sup> TRI/Environmental, Inc., Test results for the Interface Friction/Pull-out Testing # E2128-01-06, 1999