Properties of the new laser welded geogrid made of extruded bars

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ABSTRACT: Extruded polymer bars have been used for tensile strength applications for years. New technologies have extended the range of applications of these bars to soil reinforcement. One of these new techniques is laser welding technology to connect separate extruded bars together. This process results in a very consistent production quality and low strength reduction due the optimum welded area between the bars. Such production technology results in 'welded geogrids'. The new laser welded geogrids combine the properties of both stiff extruded geogrids and flexible geogrids and can be made of various polymers. The welding technique creates rigid connections while the most suited polymer can be selected to fulfil the required properties in the application. Polyester (PET) welded geogrids are used in soil reinforcement for long term applications like steep slopes and segmental block walls. Polypropylene (PP) welded geogrids are used in soil stabilization applications like subbase stabilization of roads on soft soils.
This paper presents the two laser welded geogrid types, their production technology and the results on index tests and performance tests related to their application area.

1 INTRODUCTION

A new type of geogrid has been introduced in 1999: welded geogrids. By using the latest technology of both production and material, it was possible to create a new grid-structure(1). Before the introduction two generic geogrid types were available in the market: woven geogrids and extruded geogrids.

Extruded geogrids are made of extruded sheets that are stretched after holes have been punched into them. The connection strength between the bars, the so-called junction strength, is high because the structure is monolithic.

Woven geogrids are mostly made of polyester (PET) yarns and coated with a PVC coating. The yarns are high oriented and have good creep properties. The coating gives protection to the yarns against mechanical damage and ultra violet attack. The junctions between the length and cross bars have a lower strength compared to the extruded geogrids. Until today this junction strength has caused many discussions as it is often used as an argument to make a specification exclusive for certain products. In fact, the required level of the junction strength should be evaluated in pull out tests and cannot be set as equal to the strength of the length bar.

Colbond Geosynthetics (formerly Akzo Nobel Geosynthetics) has been involved in the development of a new welded geogrid. By using laser welding technology it was possible to fulfil the requirements set for a new geogrid. During the development the product has been tested on index tests and performance tests. This paper presents the new welded geogrids, the laser welding technique and the results of all these testing.

2 DESCRIPTION OF THE WELDED GEOGRID

The welded geogrid is made from extruded polymer bars, connected at the junctions by welded material. The welded material is heated up by a laser light. Two generic types of geogrids are available:

- Uniaxial geogrids made of polyester (PET) extruded bars, called Enkagrid PRO, with a strength range of 40 till 180 kN/m (Figure 1)
- Biaxial geogrids made of polypropylene (PP) extruded bars, called Enkagrid MAX, with a strength range of 20 till 40 kN/m (Figure 2)

The geogrids are made of black bars in the longitudinal direction and have double transparent bars in the transverse direction. The structure of double transparent bars are used to increase the soil-grid interaction properties. The aperture sizes vary from 44 mm x 42 mm to 44 mm x 44 mm for the biaxial geogrids and 94 mm x 36 mm to 94 mm x 44 mm for the uniaxial geogrids. The dimensions of the welded geogrids can easily be changed within the production facility. Roll sizes are 5 m wide and 100 m long.

3 LASER WELDING TECHNOLOGY

The laser light passes the transparent bar and heats a very small layer of the black bar (Figure 3). It is very important that the heated layer is very thin to prevent distortion of the stretched molecules in the extruded, oriented bars. Also a minimum of material is being used for the connection to create an economical grid-structure. The polymer material is mixed in this very thin interface layer and in this way forms the connection. With the laser welding technique it is possible to control the energy which is absorbed by the black bar through variations in light intensity and the welding speed. An example of the microscopic thin interface layer is given in Figure 4.

Due to this thin layer an extra sacrificing layer has been created which protects the bar from mechanical and environmental attack. The tensile strength is activated by (100-2x) % of the bar section in which x is the welded area (Figure 5).

4 TESTING

During the development many tests have been executed to measure both the properties and the performance. To assess the properties the following tests have been executed:

- Tensile strength tests (single bar and wide width)
- Creep tests (rupture and strain), including accelerated tests
- Installation damage tests
- Durability tests

To asses the performance of the laser welded geogrids the following tests have been executed:

- Pull out tests
- Direct shear tests

5 INDEX TESTS

5.1 *Tensile strength tests*

Tensile strength tests have been performed on both single bars and on wide-width in accordance with EN ISO 10319. The normalized load-strain curves for the tensile strengths are presented in

Figure 6. The tensile strength presented in datasheets is the Quality Control tensile strength which is a value presented as the lower 95% confidence limit.

5.2 *Creep tests*

Creep tests have been executed according to EN ISO 13431 to measure the creep-strain and creep-rupture on single bars and on geogrid samples with representative width. To have more insight in the long-term behavior of extruded PET-bars, ERA Technology Ltd. in the UK has executed SIM (Stepped Isothermal Method) tests. Another paper in this EuroGeo 2 conference presents and evaluates these results(2). This paper also includes the creep-rupture line and the creep-strain lines.

The results are:	rupture strength at 10 years:	71.6% of Ultimate Tensile Strength (UTS)
	at 50 years:	69.5% of UTS
	at 100 years:	68.7% of UTS
	at 120 years:	68.4% of UTS

The creep-rupture results are better than those of PET-geogrids made of yarns. Within the stretched bar, the molecular chains are very nicely oriented. This orientation inside a single bar is higher than the bundle of yarns together.

5.3 *Installation damage tests*

TRI/Environmental in Austin (USA) has executed fullscale field-tests according to the method developed by Watts and Brady(3) and modified this procedure to conform with ASTM D 5818 requirements(4). Relatively small damage was measured for the welded geogrids due to the sacrifice layer (Figure 5). No junction-rupture was noticed in all installation damage tests. In table 1 the range of the reduction factor for the polyester geogrid for several soil types is presented. Table 2 presents this range for the biaxial polypropylene welded geogrid.

Table 1. Installation damage factor for PET welded geogrids

Silty loam (< 1 mm)	1.03 – 1.07
Sandy gravel (< 20 mm)	1.11 – 1.21
Course gravel (< 75 mm)	1.21 – 1.39

Table 2. Installation damage factor for PP welded geogrids

Sandy gravel (< 20 mm)	1.02 – 1.04
Course gravel (< 75 mm)	1.01 – 1.05

Figure 7 shows the test field at TRI/Environmental in which the laser welded geogrids have been tested on installation damage.

5.4 *Durability tests*

More and more the durability properties of polyester (PET) are assessed by measuring the Molecular Weight (Mn) and the Carboxyl End Group Content (CEG). For the Washington State DOT the minimum value of the Mn is 25,000 and the maximum CEG is set to be 30(5). The Mn of the welded PET-geogrid is 30,800 measured to ASTM D 4603. The CEG is 12.7 measured in accordance with GRI testmethod GG7. The geogrids do not contain post-consumer recycled material.

Hydrolysis tests have been executed in accordance with the requirements of ENV 12447. This standard requires hydrolysis testing at 95 ^{o}C, pH of 7 for 28 days. The requirement is that the retained strength should be minimal 50 %. For the PET welded geogrid a value of 64 % was determined. This means that the retained strength is much better than is expected for the use of the default value.

The effects of weathering (UV-light) on the PET geogrids has been tested according to EN 12224 which requires a minimum of 80 % retained strength after the tests. The black longitudinal bars contain carbon black to resist UV-attack. The polymer of the transparent tranverse bars contains a standard UV-stabilizer.The retained strength of the PET welded geogrid is 98.3%. The geogrid samples didn't show any damage and the junctions were intact.

Based on the executed tests, a conservative reduction factor for durability is set as presented in table 3. More research will be done in the coming period on the durability-aspects of the PET-welded geogrid.

Table 3. Durability reduction factor for PET welded geogrids

pH < 4	1.10
4.1 < pH < 9.0	1.00
9.0 < pH < 10.0	1.15

6 PERFORMANCE TESTS

6.1 *Pull out tests*

Pull out tests have been performed on both the polyester and the polypropylene welded geogrids. The tests have been done in accordance with ASTM 2467 at GeoSyntec[6], Atlanta. The values found vary between 0.8 – 1.0 for concrete sand. The default value of the coefficient of interaction (Ci) for PET geogrids is 0.8.

The PP geogrids have been tested on pull out in aggregate base course. The Ci value is 1.0.

6.2 *Direct shear tests*

Direct shear tests with the laser welded geogrids in concrete sand have been executed to determine the coefficient of direct sliding (Cds). These tests have been done in accordance with ASTM D 5321 at TRI/Environmental[7]. The Cds for PET geogrids in concrete sand is 0.87. The PP geogrids have been tested in sandy gravel which resulted in a Cds value of 0.93.

7 CONCLUSION

- A new welded geogrid has been introduced into the market, next to the existing extruded and woven geogrid types.
- Based on the results of both the index tests and performance tests, the laser welded geogrids are suited for any kind of soil reinforcement application.
- The production process is discussed. Using a laser for the welding process creates a very efficient use of the material components.
- The creep results give higher values than the existing woven PET-geogrids. This is caused by the use of highly oriented bars rather than yarns. The rupture strength at 120 years is 68.4% of the ultimate tensile strength.
- Not only carbon black but also other (transparent) UV-stabilizers in the polymer can be used to resist UV-attack.

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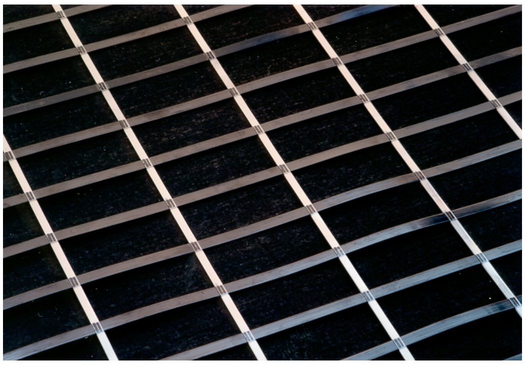

Figure 1. Welded PET-geogrid

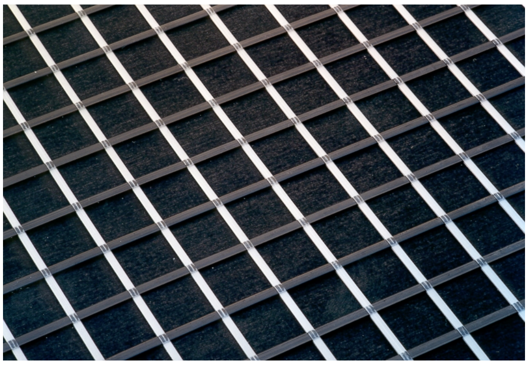

Figure 2. Welded PP-geogrid

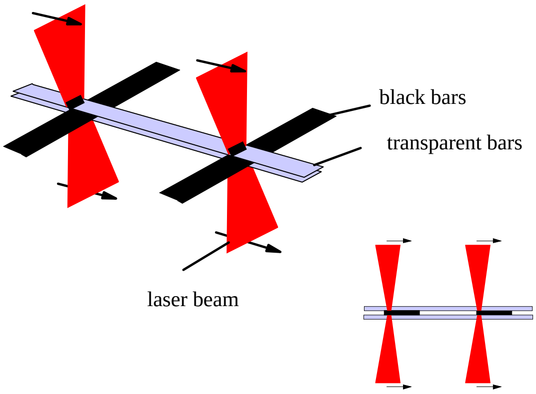

Figure 3. Laser welding process

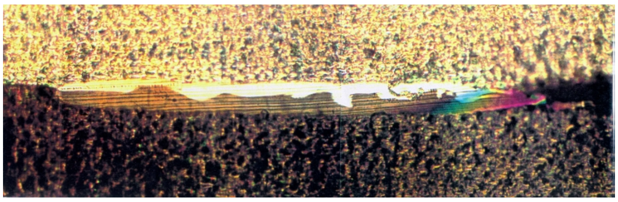

Figure 4. Electronic microscope enlargement of welded connection

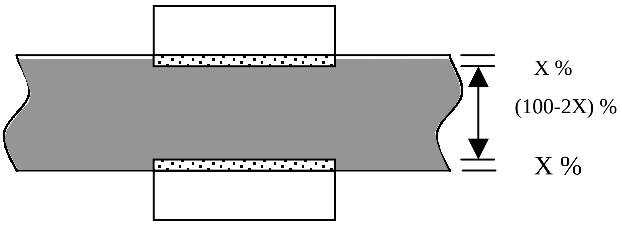

Figure 5. Sacrifice layer due to laser welding process

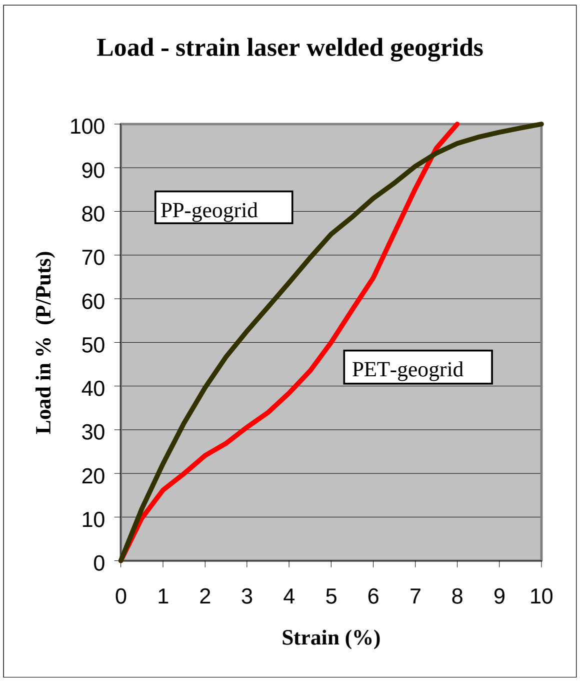

Figure 6. Normalized load-strain curves

Figure 7. Overview of test-field for installation damage tests