Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Civil and Environmental Engineering

Henrik Faye

# Geotextiles and geogrids based on basalt

## Properties and test methods

Master's thesis in Civil and Environmental Engineering
Supervisor: Rao Martand Singh
Co-supervisor: Arnstein Watn
June 2022

NTNU
Norwegian University of
Science and Technology

Henrik Faye

# Geotextiles and geogrids based on basalt

## Properties and test methods

Master’s thesis in Civil and Environmental Engineering
Supervisor: Rao Martand Singh
Co-supervisor: Arnstein Watn
June 2022

Norwegian University of Science and Technology
Faculty of Engineering
Department of Civil and Environmental Engineering

NTNU
Norwegian University of Science and Technology

# Preface

This master's thesis is written as part of the Civil and Environmental Engineering Master's Degree Programme at NTNU in Trondheim. Is is written for the course TBA 4900. The master's thesis is carried out during spring 2022 at the Department for Civil and Environmental Engineering at NTNU. The topic for the thesis was suggested by Arnstein Watn at NTNU. The study is carried out in collaboration with supervisors at NTNU, the Norwegian Public Roads Administration, Sintef and KIWA, and with help from EB Marine, Huesker and ReforceTech.

Trondheim, 2022-06-09

Henrik Faye

## Acknowledgment

Thank you Prof. Rao Martand Singh and Arnstein Watn at NTNU for supervising me. We have had almost weekly contact and good conversations related to the topic. I am very grateful for that. I want to express my sincere gratitude to Christian Recker at Sintef in Germany for organizing testing at KIWA GmbH (former TBU) and meetings with Huesker. Also, lots of thanks to the staff at KIWA GmbH for support with testing and for sharing your experiences, and thanks to Arnstein Watn for this connection. I would also like to thank the staff at the Norwegian Public Roads Administration and NTNU for help with testing.

Further thanks are extended to Andreas Elsing from Huesker Synthetic GmbH in Gescher, Germany for sharing your knowledge on the topic. I would also like to thank Martin Napierala from EB Marine in Stavanger, Norway and Len Miller from ReforceTech in Røyken, Norway for providing your products for testing.

It has been interesting to visit different laboratories, experience how the laboratories are testing, and talk to people who care for their profession. I also greatly appreciate being shown other parts of the laboratories and for discussions that have not been of interest to the thesis. Thank you for all the enthusiasm you have shown, to everyone involved! There are many experiences I have gained through this that I will take with me in my working life.

H.F.

## Abstract

The applications for geotextiles and geogrids within geotechnical engineering are many. They may provide cheaper and easier constructions than conventional structures. The soil-reinforced matrix consisting of soil and the reinforcement material has both compression and tensile capacity, whereas soil alone has limited tensile capacity. The tensile capacity depends on the materials used as reinforcement.

The majority of existing geosynthetics and geo-related products are polymer based. There is a willingness to cut the use of plastics due to environmental aspects and a growing focus on sustainable solutions. Geotextiles, geogrids and other geo-related products made from basalt fibers are proposed as a solution. Basalt is a rock material found all over the world, and fabrics can be made from fibers produced from the rock material. To assess whether basalt may be suitable or not for these products, physical, mechanical and hydraulic testing is performed. An evaluation of key properties obtained and the test methods used is performed. The test results and the overall picture of basalt products' suitability is discussed.

Two basalt products are tested throughout this study. Further three products have already been tested and data from these tests are evaluated. The wide width tensile test is the most important mechanical test for geotextiles and geogrids. All of the products are tested according to ISO 10319 in wide width tensile tests. Some of the products are also tested according to ISO 10722 for mechanical damage under repeated loading caused by granular material. This test is relevant as it simulates the conditions in the field during installation. Testing according to ISO 12224 to determine the resistance to weathering and ISO 12225 to determine the microbiological resistance has been performed. These tests indicate how the material reacts to the environments it may be placed in. Further on, creep rupture tests according to ISO 13431 have been performed. Long time creep tests that are still ongoing have been evaluated. The test results give a clear impression of what kind of properties the material possesses.

Some experiences were made while testing the basalt products. One of the main challenges related to tensile testing is the grips and the slippage that may occur. Several measurements were taken to try to avoid this. Different clamps as the split capstan, mechanical clamps with wavy insides and hydraulic clamps with various faces have been used. The products have been protected with duct tape, cardboard, nonwovens, PU-foam, and two different epoxy types in the grip area. Hydraulic clamps with faces made from Vulkollan proved to give the best results. Another challenge was the low strain and the importance of accurate strain measurements. Video extensometers or more advanced ones give the best results.

The tested basalt geogrids had a tensile strength varying between 54 and 74 kN/m. The tested basalt geotextile had a tensile strength of approximately 230 kN/m. These values are found for similar products made from polymers. All of the products had a maximum strain between 2 and 3 % at failure. These values are relatively low. The basalt products were not significantly affected by weathering or microbiologically active environments. The long term creep is close to zero when subjected to a force of 40 % of the tensile strength. The products are less flexible than synthetic ones. Damages caused by granular materials or other factors may offer problems.

The tensile strength alone would make the products appropriate for many applications in the built environment. The low strain and brittle nature of the basalt fibers is a challenge and limits the applications. Basalt fibers

are not a threat to nature when degraded in the same way plastic fibers are. Possible applications for basalt products could be in marine applications and other areas in or near river systems, as the basalt products will not emit microplastics in the same way as polymers will. Another possible application is in road construction. Many of the challenges related to basalt products are not solved yet. Until they are, polymer based products will be preferred to basalt products when their properties, availability and commercial aspects are considered.

## Sammendrag (Norwegian)

Geotekstiler og geonett brukes til ulike formål innen geoteknikk. De kan gi billigere og enklere konstruksjoner enn konvensjonelle metoder. Det sammensatte materialet som da består av jord- og armeringsmaterialet i samvirke vil ha både kompresjons- og strekkapasitet, mens jord alene har begrenset strekkapasitet. Strekkapasiteten er avhengig av hva slags materiale som brukes som armering.

De fleste eksisterende geosynteter og geo-relaterte produkter er polymerbaserte. Det er er et ønske å kutte i bruken av plast på grunn av miljøaspekter og et økende fokus på bærekraftige løsninger. Som et resultat har basalt blitt foreslått brukt i geotekstiler, geonett og andre geo-relaterte produkter. Basalt er et steinmateriale som finnes over hele verden, og stoffer kan lages av fibre fra dette steinmaterialet. For å vurdere om basalt kan være egnet eller ikke for disse produktene, er det utført fysiske, mekaniske og hydrauliske tester på utvalgte produkter. Viktige egenskaper er funnet gjennom testing og testmetodene som er brukt er evaluert. Testresultatene og helhetsbildet av basaltprodukters egnethet til geotekniske formål er diskutert.

To basaltprodukter har blitt testet gjennom studien. Ytterligere tre produkter er allerede testet og data fra disse testene er evaluert. Strekktesting er den viktigste mekaniske testen for geotekstiler og geonett. Alle produktene er testet i henhold til ISO 10319 for strekkprøving på brede prøvelegemer. Noen av produktene er også testet i henhold til ISO 10722 for mekanisk skade ved gjentatt belastning forårsaket av granulært materiale. Denne testen er relevant da den simulerer forholdene produktet blir utsatt for under installasjon. Det er utført testing i henhold til ISO 12224 for bestemmelse av motstandsdyktighet mot forvitring og ISO 12225 for bestemmelse av mikrobiologisk motstand. Disse testene indikerer hvordan materialet reagerer på miljøene det kan plasseres i. Videre er det utført krypbruddstester ved strekkbelastning i henhold til ISO 13431. Langvarige kryptester, som fortsatt pågår, er evaluert. Testresultatene gir et klart inntrykk av hva slags egenskaper materialet besitter.

Noen erfaringer ble gjort under testing av basaltproduktene. En av hovedutfordringene ved strekktesting er knyttet til grepene og glidningen som kan oppstå. Det ble gjort flere tiltak for å prøve å unngå dette. Det er brukt ulike klemmer som delt kapstan, mekaniske klemmer med bølget innside og hydrauliske klemmer med forskjellige overflater. Produktene har blitt beskyttet med gaffatape, papp, ikke-vevde produkter, PU-skum og to forskjellige epoksytyper i kontaktflaten mellom grepene og prøvestykket. Hydrauliske klemmer med Vulkollan i kontaktflaten viste seg å gi best resultat. En annen utfordring var den lave tøyningen og viktigheten av nøyaktige tøyningsmålinger. Videoekstensometre eller mer avanserte varianter gir best resultater.

Geonettene som ble testet hadde en strekkfasthet som varierte mellom ca. 54 og 74 kN/m. Geotekstilen som ble testet hadde en strekkfasthet på ca. 230 kN/m. Tilsvarende verdier finnes for lignende produkter laget av plast. Alle produktene hadde en maksimal tøyning mellom 2 og 3 % ved brudd. Disse verdiene er relativt lave. Basaltproduktene ble i liten grad påvirket av forvitring eller mikrobiologisk aktive miljøer. Produktet kryper tilnærmet ikke når det er utsatt for en kraft på 40 % av strekkfastheten over lang tid. Produktene er mindre fleksible enn tilsvarende syntetiske produkter. Skader forårsaket av granulære materialer eller andre faktorer kan by på problemer.

Strekkstyrken alene vil kunne gjøre produktene passende for bruk i geotekniske formål. Den lave tøyningen og sprø oppførselen til basaltfibrene er en utfordring, og begrenser bruksområdene. Basaltfiber er ikke en trussel mot

naturen når de brytes ned på samme måte som plast er. Mulige bruksområder for basaltprodukter kan være i marine konstruksjoner og i konstruksjoner i eller nær elvesystemer, ettersom basaltproduktene ikke vil avgi mikroplast på samme måte som polymerprodukter vil. Et annet bruksområde kan være i veibygging. Mange av utfordringene knyttet til basaltprodukter er ikke løst ennå. Inntil de blir det, vil polymerprodukter foretrekkes fremfor basaltprodukter når deres egenskaper, tilgjengelighet og kommersielle aspekter tas i betraktning.

# Contents

# List of Figures

# List of Tables

# Chapter 1

# Introduction

## 1.1 Background and motivation

Rawal et al. (2016) stated that geotextiles are one of the fastest-growing sectors of the technical textile market. Since then a lot has happened within the industry. New production methods allow for new weaving and warping techniques, new materials to be used, composite products put together with new materials and a great variety of different coatings to be developed. A greater focus on sustainable solutions is a driver for this evolution. Although synthetic fibers are most used for geotextiles, geogrids and other geo-related products, natural fibers should not be ignored. Natural fibers are already in use in many countries, especially in developing countries. Among them are plant fibers like jute, hemp and flax, fruit fibers from coconut husk and other plants, and leaf fibers (Singh & Venkatappa Rao 2006). Animal fibers such as wool and silk may also be used to produce geo-related products. The same goes for mineral fibers such as asbestos or basalt, and basalt is an interesting material for this task. There are great resources available worldwide.

As the focus on environmentally friendly solutions in the built environment is increasing new materials are being studied. Most geotextiles and geogrids in use today are based on synthetic materials, often petroleum-based. The production of these materials have a negative impact on our environment. Microplastics is yet another problem. Recent studies show that plastic materials will leave fragments over time. These fragments takes long time to degrade and will disrupt the ecosystems where they are deposited (Cózar et al. 2014; Hale et al. 2020; Petersen & Hubbart 2021; Horton & Dixon 2018). This is especially the case in or near river systems and in the sea, where the fragments are transported and deposited by the water. Compared to polymer products the basalt ones may be more environmental friendly with respect to production and substances that are released. They are natural and have their place in the ecosystem already.

Most geotextiles in use today are based on synthetic materials, often petroleum-based. The production of these materials have a negative impact on our environment. Microplastics is yet another problem. Recent studies show that plastic materials will leave fragments over time. These fragments takes long time to degrade and will disrupt the ecosystems where they are deposited (Cózar et al. 2014; Hale et al. 2020; Petersen Hubbart 2021; Horton Dixon 2018). This is especially the case in or near river systems and in the sea, where the fragments are transported and deposited by the water. How they are transported is hard to analyze. Natural materials without same problems regarding degradation exists. Unfortunately, their service life is often significantly shorter, and most of them do not have the properties that modern engineering needs.

The initiative to study this particular material came from Martin Napierala in EB Marine and Arnstein Watn at NTNU. Napierala had contacted Watn regarding a project in Germany where a problem related to the river Dalbach near Essen had occurred. The project involved a solution where geotextiles were intended to be used. Due to a desire to avoid the use of polymer based products due to microplastics the possibility of using basalt products came up. EB Marine have access to such products.

Due to coincidences, ReforceTech was also involved through Len Miller. They mainly work with reinforcement products for concrete based on basalt and glass fiber composites (ReforceTech AS 2022). Within this field, they have a lot of experience. The company also distributes a geogrid based on basalt. They do not sell very much of this product and they do not have much data on it. However, they were interested to know if the product had potential.

## 1.2 Problem formulation

How well-suited basalt products are for geotechnical problems is yet to be sufficiently assessed. Important issues to investigate are what properties the material has in the form of geo-related products, how competitive it is compared to already existing solutions, the value chain and the pricing of the products, environmental and health aspects related to the products, and public requirements that may affect them.

Not much research is available on the mechanical, hydraulic or chemical properties of geo-related products made from basalt. There is in general a limited range of research available to the public on this although some exist. The existing papers are mostly on basalt fibers in general and not specific for use in geotechnical engineering. The study will focus on geotechnical properties and applications. Based on this and the issues mentioned in the previous paragraph the main objectives of the thesis are the following:

- Perform standardized tests in the laboratory to find mechanical, physical and hydraulic properties for a selection of geo-related products based on basalt
- Discuss challenges related to testing of products based on basalt fibers
- Evaluate suitable applications for geo-related products based on basalt fibers

## 1.3 Approach

The majority of the time and effort has been put into testing geo-related basalt products. The products tested are a geotextile made of 100 % basalt supplied by EB Marine and a geogrid mainly made of basalt supplied by ReforceTech

AS. They were received in January and February 2022. Both have been tested at NTNU in Trondheim, Norway, at Statens Vegvesen in Oslo, Norway and at KIWA in Greven, Germany.

The testing at NTNU was carried out as preliminary testing in the end of February and start of March 2022. Tensile tests were carried out on an old, renovated rig. The results can not be used as they are not reliable, but valuable experience was gained. The tests were carried out in the end of February and the start of March 2022. Further testing took place in Statens Vegvesen's laboratories. A week in the middle of March 2022 was spent here where further knowledge on the products was gained. Both tensile tests and permeability tests were carried out. The main work was done in and near Münster in Germany in the end of April 2022. A visit was made to FH Münster to exchange experiences and to study the products in a microscope. The laboratory testing took place at KIWA's facilities outside of Münster in Greven. Damage testing and tensile testing were done on both products. KIWA have some knowledge on basalt products and a lot of knowledge on geosynthetics and testing in general which was of great help. A meeting with Huesker was arranged. Huesker is one of the leading manufacturers of geosynthetics in the world. They have done research and development on basalt products, and had interesting points of view to share.

Literature studies have been carried out. A project thesis in the form of a literature study on the properties of synthetic and natural-based geotextiles and their environmental impact was carried out in the autumn of 2021. This was a part of the course TBA4510 at NTNU. Further literature studies have been carried out for this master's thesis.

## 1.4 Limitations

Several limitations are introduced:

- Geosynthetics may come in endless shapes and forms. A selection of geotextiles and geogrids are tested. Other products may have been developed and may be on the market, that may possess different properties. The thesis will only cover the involved products and may therefore exclude findings from other products that could be of interest.
- The tests performed are selected to find properties that are important for reinforcement purposes and due to accessibility. Physical and mechanical tests as the Determination of the characteristic opening size (ISO 2019b), Static puncture test (ISO 2006a) and Dynamic perforation test (ISO 2006b) should be performed. Due to limited time, it is not done in this thesis.
- Field tests should be carried out as well as laboratory tests. Due to limited time, it is not done in this thesis.
- Basalt may be an ideal material to use in a composite matrix. This aspect will not be covered in this thesis.

## 1.5 Reference to preliminary study

In autumn 2021 a preliminary study was carried out as mentioned previously. The result of this study was an unpublished project thesis titled *Geotextiles based on basalt for erosion control and reinforcement purposes* by Faye (2021). Parts of this master's thesis are adopted from this work, possibly with modifications. This is especially the case for Chapter 2 - Literature study, Chapter 8 - Discussion, and Chapter 9 - Conclusion and recommendations for further work.

## 1.6 Structure of the report

The thesis consists of 9 chapters. Chapter 1 presents the background and motivation for the study as well as the objectives, approach and limitations. Chapter 2 gives an introduction to the topic of geosynthetics and the rock material basalt. In chapter 3, the previous testing done by Huesker and KIWA is presented and discussed. Chapter 4 presents the two products that have been tested in spring 2022. Chapter 5 presents the standard for damage testing, and the results obtained at KIWA are presented and discussed. Chapter 6 is built up in the same way. The standard for tensile testing is presented. Thereafter the testing performed at NTNU, at Statens Vegvesen and at KIWA is presented and discussed. The same goes for chapter 7 where the standard for permeability testing is presented followed by the results obtained at Statens Vegvesen and a discussion. In chapter 8, the results and experiences are discussed. Challenges regarding tensile testing are discussed and the properties of the basalt products as well. An evaluation of the products' applicability is then performed. Chapter 9 gives a conclusion and recommendations for further work.

The study is based on literature studies, results obtained from the previous testing by others and results obtained from testing by the author. It is more or less structured so that the literature study is presented first, followed by the previous tests performed and thereafter the tests performed throughout spring 2022. When the tests are presented, they are briefly introduced before the results are presented and then discussed. The discussion in chapter 8 and the conclusion and recommendations for further work in chapter 9 are based on all the separate discussions in chapters 3, 5, 6 and 7.

# Chapter 2

# Literature study

A preliminary literature study was carried out in autumn 2021. The study dealt with what a geotextile is, how it is produced, what functions it has and what applications it is used for. Mechanical properties for typical synthetic materials used were found, and compared to those of natural fibers, among them basalt. Advantages and challenges for both synthetic and natural materials were addressed. The preliminary literature study is found in the appendix.

As a preliminary literature study has been carried out already this chapter will only cover the topic of geosynthetics briefly. For more information regarding production methods and an overview of the materials typically used, both synthetic and natural, reference is made to this study. The study also deals with typical functions and applications for geosynthetics. Basalt as a rock material and basic geological aspects are not sufficiently studied in the preliminary literature study. They will be covered in more detail in this chapter.

## 2.1 Geosynthetics

The name geosynthetics is the collective term for products that are intended to work in conjunction with soil to solve various problems. They may solve problems related to separation, reinforcement and filtration (NorGeoSpec 2012). They come in many different shapes and the most common ones are geotextiles and geogrids. Other types are geonets, geomembranes, geosynthetic clay liners, geofoam, geocells and geocomposites. These products are often made of synthetic materials but might as well be made from natural materials. The name geosynthetics does not convey this in a good way. The literature gives different definitions of what a geosynthetic is. Some sources say that geosynthetics are made from synthetic materials while others say that geosynthetics may be made of synthetic or natural materials. The standard ISO 10319 states in the scope that a geosynthetic may be polymeric, glass, or metallic. Although the collective term does not make it clear that the products do not have to be made of synthetic materials, it should be noted.

### 2.1.1 Geotextiles

According to Langley & Kim (2006) geotextiles are defined as "any permeable textile material used for filtration, drainage, separation, reinforcement and stabilization purposes as an integral part of civil engineering structures of earth, rock or other construction materials".

The products are made in the same way as traditional textiles. The most common types of geotextiles are nonwovens, wovens, knitted and composites.

Nonwoven products are the most common ones because of their cost and performance. These types are often produced from spunbonding or needle-punching. Needle-punching is the most common one (Bérubé & Saunier 2016). They can be made from short-staple fibers or continuous filaments. As of today polypropylene (PP) dominates because of its' low cost, low specific gravity and strength (Faye 2021). However, these products are not as strong as wovens and knitted products. They have a lower strength and higher strain. They are typically used for separation, filtration and protections.

Woven products are made from yarns, filaments or slit film tapes. The threads are creating a fabric by interlocking two or more threads at right angles. The threads extend in the machine direction (MD) and the cross machine direction (CMD), or vertically and horizontally. The vertical threads are called the warp while the horizontal threads are called the weft. The warp and weft are woven together in a plain weave, twill weave or satin weave. Woven products tend to have higher strength properties compared to nonwovens and are not elongated to the same extent as nonwovens and knitted products. These types of products are popular in reinforcement applications.

It is also possible to make knitted geotextiles. In the knitting process, continuous yarns are intertwined to form repeated loops. The loops are linked together to form a web. Weft knitting and warp knitting are the most common knitting processes. The density of the product can be varied. In general, the knitted products will tend to stretch more than the wovens due to their structure.

In Figure 2.1 a woven, nonwoven and knitted fabric is shown (Patel 2019).

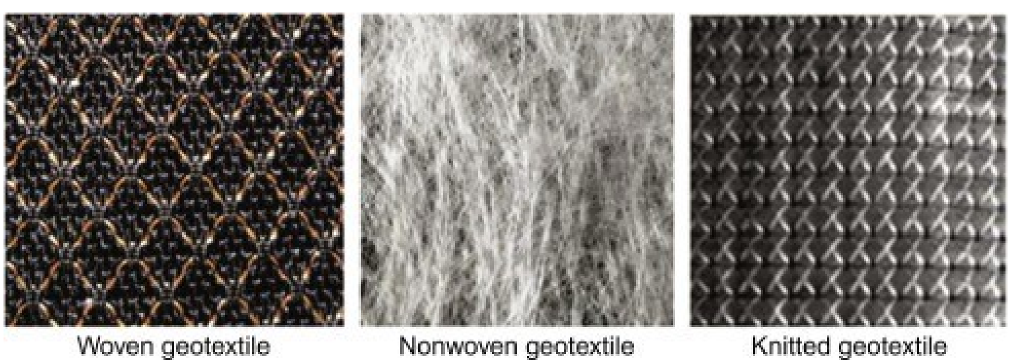



Figure 2.1: Woven, nonwoven and knitted geotextiles (Patel 2019)

### 2.1.2 Geogrids

Geogrids are made up of connected parallel tensile ribs in longitudinal and transversal directions, with relatively large apertures. This allows soil and stones to strike through the openings and create an interlocking effect with the soil. The tensile forces may be transferred from the transversal ribs through the junctions or nodes to the longitudinal ribs. The strength of both the ribs and the junctions are therefore of importance. The products may be woven or knitted from yarns. For polymer materials, heat-welding processes are common as well as punching or cutting out patterns from a sheet of material to produce the geogrid.

Geogrids are often used for reinforcement purposes. It is common to use the solution for road and railway improvements, as well as for embankments on soft soil, for reinforcement of steep slopes, to build retaining walls, and erosion control.

They may come in the form of uniaxial, biaxial or triaxial geogrids. These three types are shown in Figure 2.2 where a biaxial one is shown to the left, a triaxial one in the middle, and a uniaxial one to the right (Happho 2017).

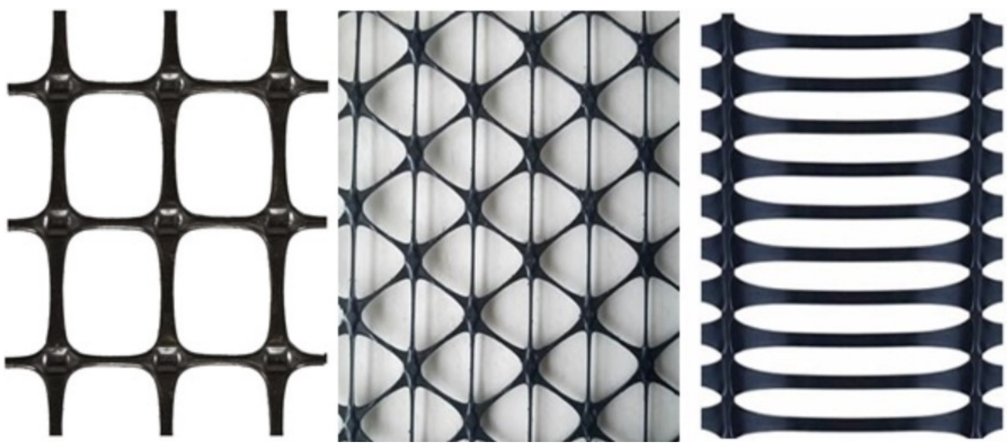
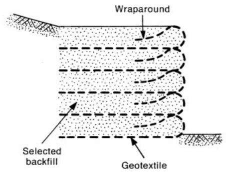


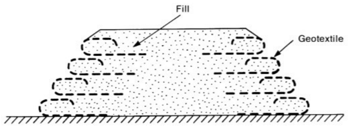
Figure 2.2: Uniaxial, biaxial and triaxial geogrids (Happho 2017)

### 2.1.3 Functions and applications

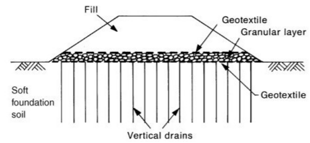
According to NorGeoSpec (2012) the functions of a geosynthetic is divided into separation, reinforcement and filtration. The same division is given in the European and Norwegian standard NS-EN 13251 (Standard Norge 2016). Koerner (2012) on the other hand categorizes the functions as separation, reinforcement, filtration, drainage and moisture barrier. In many cases, geosynthetics can replace the use of conventional structures made from concrete or steel. The typical applications are shown in Figure 2.3.



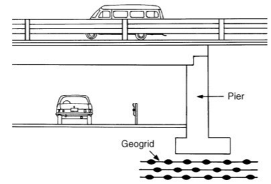

(a) Retaining wall



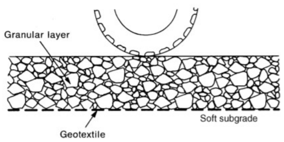

(b) Embankment with steep slopes



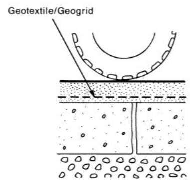

(c) Embankment on soft foundation soil



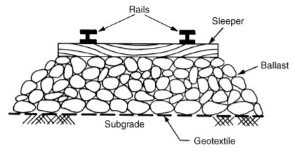

(d) Bridge pier



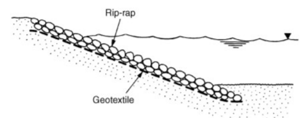

(e) Unpaved road



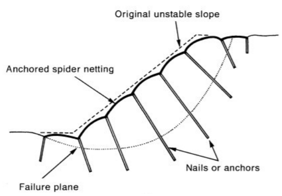

(f) Paved road



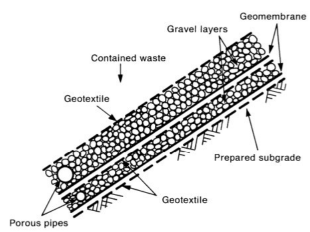

(g) Railway track



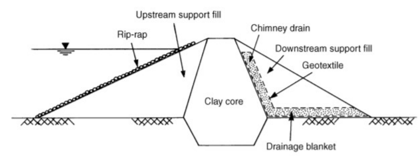

(h) Erosion control in a slope



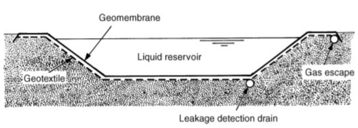

(i) Stabilization of a slope



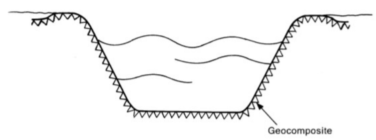

(j) Landfill



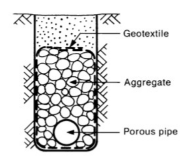

(k) Dam




(l) Liquid reservoir




(m) Water channel




(n) Trench drain

Figure 2.3: Typical applications for geosynthetics and geosynthetic-related materials (Shukla & Yin 1987)

As seen in Figure 2.3 the number of functions and applications are many. The function of the geosynthetic will vary depending on what application it is used for. For reinforcement purposes the most important properties will be the tensile strength, tearing and elongation. For separation and filtration purposes other properties will dominate. The most important properties for each function are summed up in Table 2.1 (Koerner 2012).

Table 2.1: Properties and functions of geotextiles (Koerner 2012)

| | **Mechanical properties** | | | | | **Hydraulic properties** | | |
|---|---|---|---|---|---|---|---|---|
| | **Puncture** | **Tensile strength** | **Compression** | **Tearing** | **Elongation** | **Permeability** | **Flow capacity** | **Pore openings** |
| **Separation** | x | | | x | | x | | x |
| **Reinforcement** | | x | | x | x | | | |
| **Filtration** | | | x | | | x | | x |

## 2.2 Basalt

### 2.2.1 Structure

According to Schou Jensen (2006) basalt is a fine-grained to dense volcanic rock. On fresh quarries, it is black to gray-black, while on weathered surfaces it is usually gray, light gray or reddish-brown. Basalt consists largely of the minerals calcium-rich plagioclase and pyroxene in roughly equal parts. Because the rock is fine-grained, these minerals are not visible to the naked eye. Basalt contains some iron-titanium oxides and is therefore a relatively young rock that is often weakly magnetic. Basalt can also contain the mineral olivine. The geological key features are:

- Black to grey color
- Dense, fine-grained
- $SiO_2$ content 45-52 %
- Density 2,98 $g/cm^3$

### 2.2.2 Prevalence

Of the volcanic day rocks, basalt is the most widespread. According to Dhand et al. (2015) 33 % of the earth's surface consists of basalt rock. The so-called pillow lava builds up the seabed. In addition, basalt is found in the form of large, so-called plateau basalt covers on the continents, for example in South America, Africa and India. Basalt is known from the Faroe Islands and Iceland, which are mostly built up by large, widely dispersed lava flows of plateau basalt penetrating in connection with the opening of the North Atlantic 55-60 million years ago.

When basaltic lava flows solidify, they contract and often form a characteristic hexagonal to octagonal, columnar structure. They are usually perpendicular to the direction of flow. Such can be found in Ireland at the Giant's Causeway.

### 2.2.3 Suitability

To make geo-related products, the rocks need to be converted into continuous basalt fibers (CBF). Not all occurrences are equally suitable for this purpose. Whether a deposit is suitable or not depends on the physical and chemical properties of the rock in the specific deposit. An important parameter in this regard is the number of oxides. According to Global Basalt Engineering (2022) it is favorable with the following distribution of oxides to produce CBF:

Table 2.2: Composition of basalt fibers (Global Basalt Engineering 2022; Militký et al. 2002; Deák & Czigány 2009)

| Oxides | Content [%] (Global Basalt Engineering 2022) | Content [%] (Militký et al. 2002) | Content [%] (Deák & Czigány 2009) |
|---|---|---|---|
| $SiO_2$ | 47,5-55,0 | 43,3-47 | 42,4-55,7 |
| $Al_2O_3$ | 14,0-20,0 | 11-13 | 14,2-18,0 |
| CaO | 7,0-11,0 | 10-12 | 7,4-8,9 |
| MgO | 3,0-8,5 | 8-11 | 4,1-9,5 |
| Fe total | 7,0-13,5 | - | - |
| $Fe_2O_3$ | - | <5 | 10,8-11,7 |
| $K_2O$ | 1,0-7,5 | <5 | 1,1-2,3 |
| $Na_2O$ | 2,0-7,5 | <5 | 2,4-3,8 |
| $TiO_2$ | 0,2-2,0 | <5 | 1,1-2,6 |
| MnO | up to 0,25 | - | - |

To assess whether the rock is suitable or not a sample needs to be taken and evaluated in a laboratory. The samples should then be representative for the entire field. Samples with a porphyritic basalt structure and amorphous form are desirable to produce CBF.

### 2.2.4 Deposits and production

Basalt rock can be found in almost every country. It is a very common rock type. The deposits that are suitable to produce CBF are mainly found in Ukraine, Russia, Uzbekistan, Georgia, Saudi Arabia, Ethiopia, China, India and Brazil (Global Basalt Engineering 2022). The quarries are typically found in these countries.

The same goes for the location of the production facilities. It would be an advantage both economically and logistically to produce the fibers near the quarries. According to Len Miller of the Norwegian company ReforceTech AS they used to purchase their geogrids from Kameny Vek, a Russian producer. Kameny Vek used to get their rocks from a quarry in Ukraine. Kameny Vek would produce the bobbins and then get the geogrids produced from a local manufacturer. ReforceTech would then buy the finished product.

With the political situation in the world today this is a problem for the supply chain. While this thesis is being written there is a war between Russia and Ukraine. Labour and infrastructure is knocked out of play in both countries. There are trade sanctions against Russia. The majority of basalt products being sold in Europe have their origin in Eastern European countries. The current situation highlights how vulnerable the supply chain can be.

Melting of the rocks during the manufacturing process is less energy-consuming for basalt fiber compared to glass fiber and carbon fiber according to Graubner et al. (2021). The melting process is still the most energy-consuming part of the production. Temperatures over 1 450 °C are needed to melt the rock (Turukmane et al. 2018). This process is often costly. Both short fibers and continuous fibers can be made from the rock. The continuous fibers are used in fabrics. The production process is described in the project thesis by Faye (2021).

### 2.2.5 Health issues

Basalt and asbestos are two quite similar materials. Asbestos was for a longer period a well-known and much-used material until its negative health effects were discovered. The fibers were found to be carcinogenic and have other toxicity effects due to the morphology and surface properties of the fibers (Fiore et al. 2015). The question of whether basalt fibers have the same properties or not has been raised.

According to Weddell (1990) fibers with the following properties are of concern:

- fibers with diameters less than 1,5 μm (some say less than 3,5 μm) remain airborne and are respirable;
- fibers with an l/d aspect ratio higher than 3 do not seem to cause the serious problems associated with asbestos
- fibers durable in the lungs do not cause problems if they are decomposed in the lungs.

Both during the production of the fibers and during the lifetime of the finished product polymeric and non-polymeric materials can emit spores. Non-polymeric fibers usually have a diameter greater than 3,5 μm. Militký et al. (2002) made an experiment on the abrasion of basalt fibers and found that the mean value of the fragment fiber diameter is the same as the diameter of the undamaged fiber. No splitting of fibers occurred during fracture. The study found that the l/d aspect ratio of basalt fiber fragments was 20,8 and hence greater than the critical value.

The basalt fibers may cause skin irritation. However, this should not be dangerous.

### 2.2.6 Use of basalt today

Basalt is in use in other industries today. As a pure rock material and in products made from basalt fibers. The properties of the continuous fibers are largely identical to those of the raw material.

Compared to other fiber materials it has quite similar characteristics to glass, carbon and aramid. The real competitor would in most cases be glass fibers. Compared to glass fibers the basalt fibers have quite similar geometrical and mechanical properties according to a study by Deák & Czigány (2009) in terms of diameter, tensile strength and modulus for continuous fibers. The study carried out tests on continuous basalt fibers from Kanenny Vek (Russia), Technobasalt (Ukraine) and D. S. E. Group (Israel) made from the spinneret method.

These properties have led to the material being used as a substitute for glass, carbon and aramid. It is used in the building industry as reinforcement in concrete and for applications where its' temperature properties concerning fire safety come to use. The temperature properties have proven to be useful in solutions for the automotive industry. It is also in use in the medical industry (Faye 2021).

# Chapter 3

# Previous tests

## 3.1 Previous tests from Huesker in Gescher, Germany

Manufacturers such as Huesker have tried to make products based on basalt previously. Test laboratories such as KIWA have performed testing on the prototypes of the products. The results obtained from testing have been shared and will be presented in this chapter.

The products are named Muster 08/02b, Fortrac 50/50-40 B, and Basalt product A. All of them are geogrids based on continuous basalt fibers. Due to confidentiality, the real name of Basalt product A can not be mentioned. Therefore it will be referred to as Basalt product A. It is a geogrid based on basalt with coating.

Conventional tensile tests are done on the Muster geogrid. The Fortrac geogrid has also been tensile tested but with the gripping area protected with various materials to try to obtain better results. The Fortrac geogrid has also been tested for creep rupture and long term creep. Basalt product A has been tested for resistance to weathering and microbiological resistance.

### 3.1.1 Tensile tests on Muster 08/02b basalt geogrid

Muster 08/02b is a product that has been developed and tested by Huesker in the Huesker test laboratory in 2009. The product is tested in both machine direction (MD) and cross machine direction (CMD). In MD the product has two connected strands while it has four smaller strands side by side in CMD. A picture of the product is shown in Figure 3.1.

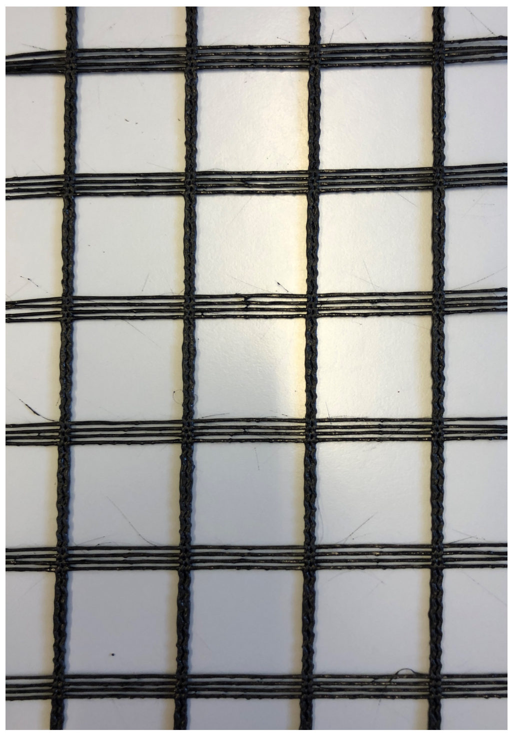


Figure 3.1: Muster 08/02b basalt geogrid

Table 3.1: Test data for Muster 08/02b basalt geogrid

| **Test data** | |
|---|---|
| Material | Basalt geogrid Muster 08/02b |
| Test norm | ISO 10319:1996-6 |
| Date | 09.03.2009 |
| Test direction | MD and CMD |
| Weight | 445 g/m2 |
| Thickness | NA |
| Width | 520/521 cm |
| Calculation | 0,86 threads/cm |
| Threads / specimen | 20 |
| Bundles / specimen | 5 |
| AP-test width | 200 mm |
| Initial load | 135 N |
| Method of sampling | ISO 9862 |
| Condition of specimen | Dry |
| Type of testing machine | Inspect 600 |
| Type of clamps | Hydraulic clamps, face NA |
| Conditioning | 20 ° C / 65 % (ISO 554) |
| F1 = Force at | 1 % |
| F2 = Force at | 1,5 % |
| F3 = Force at | 2 % |
| $\epsilon$ 1 = Extension at | 40 kN/m |

**Results**

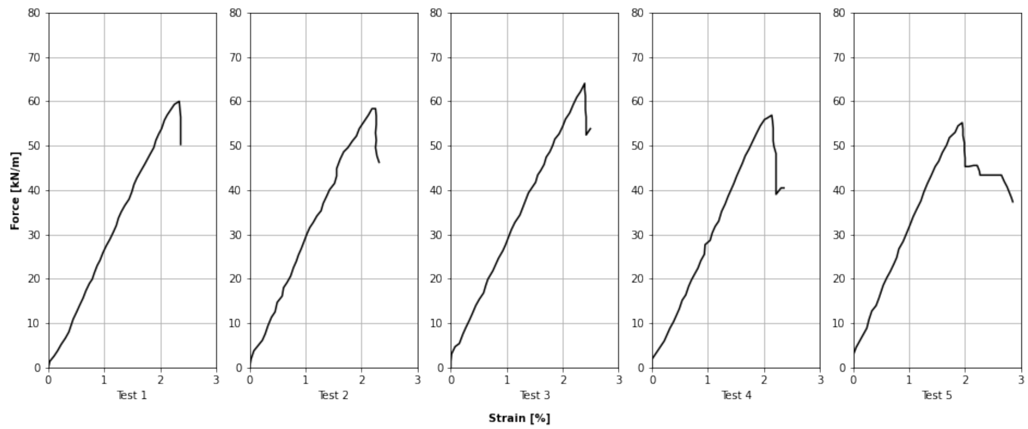



Figure 3.2: Force [kN/m] vs strain [%] for Muster 08/02b basalt geogrid in MD

Table 3.2: Statistics from wide width tensile test on Muster 08/02b basalt geogrid in MD

| n=0 | Specimen [N] | F max [kN/m] | $\epsilon$ max [%] | F1 [kN/m] | F2 [kN/m] | F3 [kN/m] | $\epsilon$1 [%] | Measurement length [mm] | Test speed [%/min] |
|---|---|---|---|---|---|---|---|---|---|
| $\bar{x}$ | 13 660,2 | 58,74 | 2,16 | 29,5 | 42,96 | 53,68 | 1,38 | 56,88 | 16,96 |
| s | 82,239 | 3,534 | 0,182 | 1,423 | 1,561 | 4,802 | 0,045 | 3,095 | 1,178 |
| V | 6,02 | 6,016 | 8,41 | 4,824 | 3,635 | 8,945 | 3,241 | 5,442 | 6,947 |

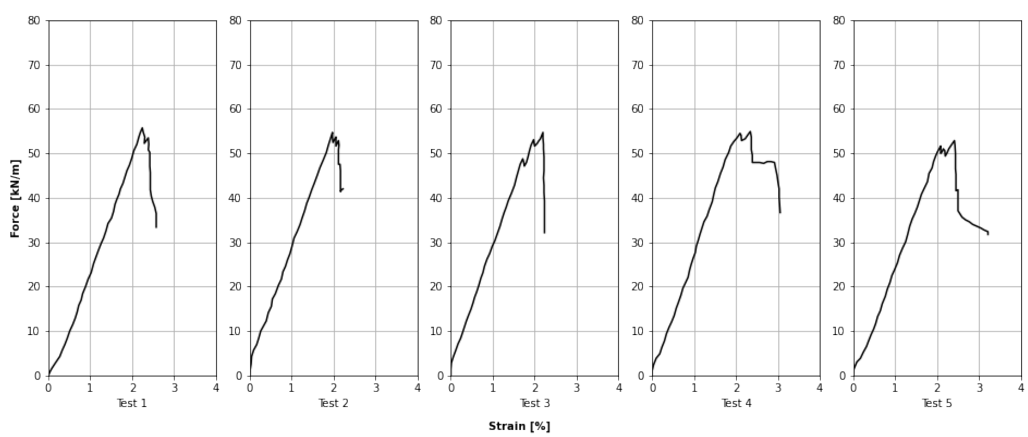



Figure 3.3: Force [kN/m] vs strain [%] for Muster 08/02b basalt geogrid in CMD

Table 3.3: Statistics from wide width tensile test on Muster 08/02b basalt geogrid CMD

| n=0 | Specimen [N] | F max [kN/m] | $\epsilon$ max [%] | F1 [kN/m] | F2 [kN/m] | F3 [kN/m] | $\epsilon$1 [%] | Measurement length [mm] | Test speed [%/min] |
|---|---|---|---|---|---|---|---|---|---|
| $\bar{x}$ | 12 829,4 | 54,52 | 2,20 | 27,4 | 40,86 | 51,72 | 1,48 | 62,2 | 19,28 |
| s | 263,83 | 1,117 | 0,187 | 2,601 | 2,995 | 1,25 | 0,11 | 4,53 | 1,293 |
| V | 20,56 | 2,048 | 8,504 | 9,493 | 7,331 | 2,416 | 7,402 | 7,284 | 6,707 |

**Evaluation of performance**

Figure 3.2 and 3.2 as well as Table 3.2 and 3.3 show the results. In MD the material obtains a mean tensile strength of 58,74 kN/m and 54,52 in CMD. It can be seen from the graphs that the material behavior is quite similar for all the tests. These tests indicate that the material is brittle.

The strain at failure was 2,16 % in MD and 2,20 % in CMD. The material is not very stretchy as expected. Compared to conventional geosynthetics the Muster geogrid has an elongation at failure which is significantly lower. Conventional products typically have a strain at failure around 10-15 %.

The results from the tests show curves that are more or less linear until rupture occurs. Some of the curves have a steeper slope in the beginning but then it flattens out some and becomes almost linear. Linear curves like these in a stress-strain diagram normally mean that the material is elastic in this area. To find out if this is the case the samples should have been unloaded and then reloaded to study the material behaviour.

After the linear area, the samples fail. Other materials like aluminum and steel would typically have a stress-strain curve with different sections with varying slopes on the curve. In the start, the curve is typically linear in the elastic area before the curve reaches a breaking point often referred to as the yield strength. After reaching the yield point the curve often flattens out and the hardening process begins. In the hardening process the stress continues to increase until the material reaches its' ultimate strength and from that point goes towards fracture.

## 3.2 Previous tests from KIWA in Greven, Germany

Fortrac is a series of geogrids made by Huesker. The standard raw material in the products has been high-modulus polyester (PET), but the Fortrac can also be made from polyvinyl alcohol (PVA), aramid and other materials. The product has been made with basalt as base material. The following tests are from the Fortrac product with basalt as raw material.

### 3.2.1 Tensile tests on Fortrac R 50/50-40 B basalt geogrid

During tensile testing on Fortrac R 50/50 specimens, problems occurred in the clamping area. Measurements were taken to avoid this. The specimens were protected with cardboard, nonwovens, PU-foam, robust hardening epoxy resin, and soft hardening epoxy resin between the specimen and the clamps.

Table 3.4: Test data for Fortrac R 50/50-40 B basalt geogrid in tensile tests

| **Test data** | |
|---|---|
| Material | Fortrac R 50/50-40 B |
| Test norm | ISO 10319:2008-10 |
| Date | From 28.03.2012 to 05.11.2012 |
| Test direction | MD |
| Condition of specimen | Dry |
| Specimen width (b0) | 46 mm |
| Test strands | 1 |
| Strands / m | 21,7 |
| Length | 100 mm |
| Pre-load | 30 N |
| Type of testing machine | Zwick Z250 |
| Load cell | 250 kN |
| Extensometer (path) | Video |
| Specimen grips | Demgen M250 |
| | Note: Clamping area protected with various materials |
| Climate | 22 ° C / 42 % relative humidity |
| F0 = Force at | 0,5 % |
| F1 = Force at | 1 % |
| F2 = Force at | 1,5 % |
| $\epsilon$ 1 = Strain at | nominal load |

**Results**

Specimens protected with cardboard tested 28.03.2012

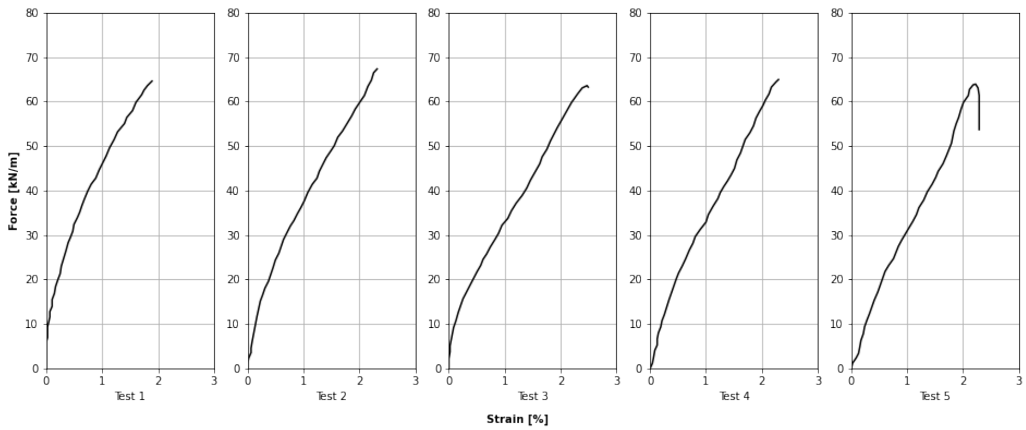



Figure 3.4: Force [kN/m] vs strain [%] for Fortrac R 50/50-40 B basalt geogrid protected with cardboard in MD

Table 3.5: Statistics from wide width tensile test on Fortrac R 50/50-40 B basalt geogrid protected with cardboard in MD

| n=5 | Fm [N] | Fm [kN/m] | Am [%] | F0 [kN/m] | F1 [kN/m] | F2 [kN/m] | $\epsilon 1$ [%] | v-test [%/min] |
|---|---|---|---|---|---|---|---|---|
| $\bar{x}$ | 3006 | 65,35 | 2,29 | 22,51 | 35,39 | 46,77 | 1,21 | 23,37 |
| s | 66 | 1,43 | 0,23 | 5,45 | 6,16 | 6,27 | 0,26 | 3,87 |
| V | 2,19 | 2,19 | 9,83 | 24,22 | 17,41 | 13,40 | 21,59 | 16,57 |

Specimens protected with nonwovens tested 28.03.2012

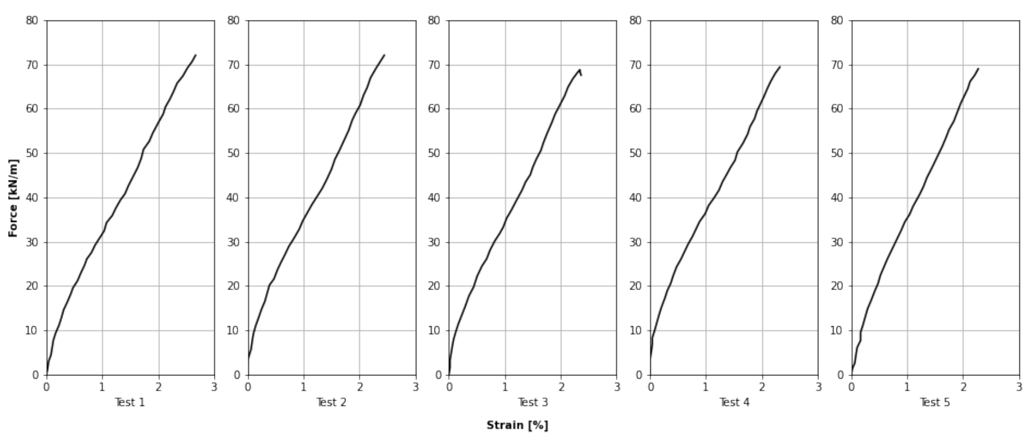



Figure 3.5: Force [kN/m] vs strain [%] for Fortrac R 50/50-40 B basalt geogrid protected with nonwoven in MD

Table 3.6: Statistics from wide width tensile test on Fortrac R 50/50-40 B basalt geogrid protected with nonwoven in MD

| n=5 | Fm [N] | Fm [kN/m] | Am [%] | F0 [kN/m] | F1 [kN/m] | F2 [kN/m] | $\epsilon$1 [%] | v-test [%/min] |
|---|---|---|---|---|---|---|---|---|
| $\bar{x}$ | 3243 | 70,50 | 2,31 | 23,25 | 35,89 | 48,43 | 1,17 | 19,50 |
| s | 76 | 1,65 | 0,16 | 2,14 | 2,04 | 2,11 | 0,09 | 1,21 |
| V | 2,34 | 2,34 | 7,11 | 9,21 | 5,68 | 4,35 | 7,45 | 6,19 |

Specimens protected with soft hardening epoxy resin tested 05.04.2012

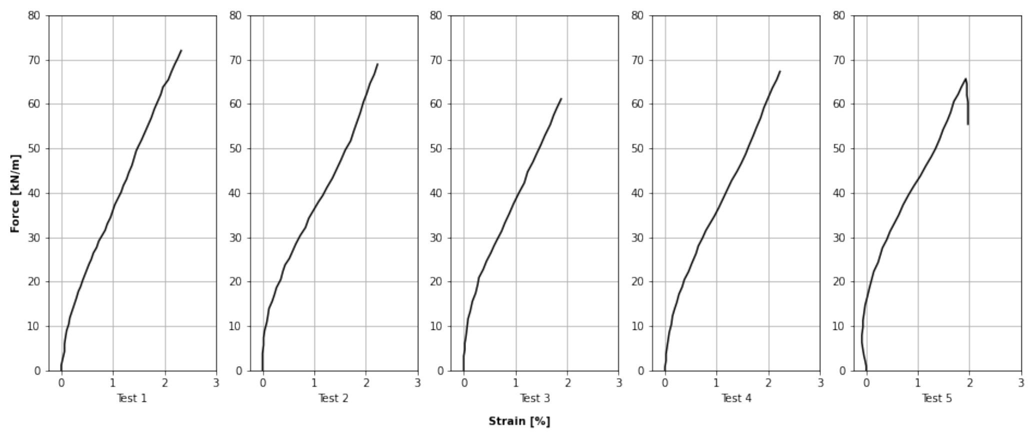



Figure 3.6: Force [kN/m] vs strain [%] for Fortrac R 50/50-40 B basalt geogrid protected with soft hardening epoxy resin in MD

Table 3.7: Statistics from wide width tensile test on Fortrac R 50/50-40 B basalt geogrid protected with soft hardening epoxy resin in MD

| n=5 | Fm [N] | Fm [kN/m] | Am [%] | F0 [kN/m] | F1 [kN/m] | F2 [kN/m] | $\epsilon$1 [%] | v-test [%/min] |
|---|---|---|---|---|---|---|---|---|
| $\bar{x}$ | 3084 | 67,03 | 2,07 | 26,23 | 38,26 | 50,87 | 1,07 | 16,75 |
| s | 195 | 4,23 | 0,19 | 3,95 | 3,21 | 3,34 | 0,14 | 2,13 |
| V | 6,31 | 6,31 | 9,21 | 15,07 | 8,39 | 6,57 | 13,47 | 12,70 |

Specimens protected with robust hardening epoxy resin tested 11.04.2012

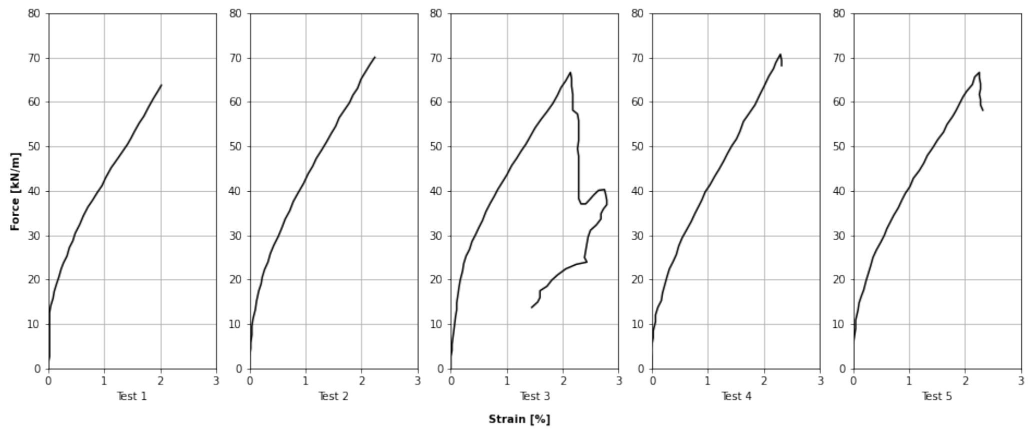



Figure 3.7: Force [kN/m] vs strain [%] for Fortrac R 50/50-40 B basalt geogrid protected with robust hardening epoxy resin in MD

Table 3.8: Statistics from wide width tensile test on Fortrac R 50/50-40 B basalt geogrid protected with robust hardening epoxy resin in MD

| n=5 | Fm [N] | Fm [kN/m] | Am [%] | F0 [kN/m] | F1 [kN/m] | F2 [kN/m] | $\epsilon 1$ [%] | v-test [%/min] |
|---|---|---|---|---|---|---|---|---|
| $\bar{x}$ | 3101 | 67,42 | 2,08 | 31,04 | 43,46 | 54,35 | 0,85 | 22,05 |
| s | 132 | 2,87 | 0,09 | 1,40 | 1,45 | 1,26 | 0,07 | 0,80 |
| V | 4,26 | 4,26 | 4,48 | 4,51 | 3,34 | 2,32 | 7,71 | 3,64 |

Specimens protected with PU-foam tested 05.11.2012

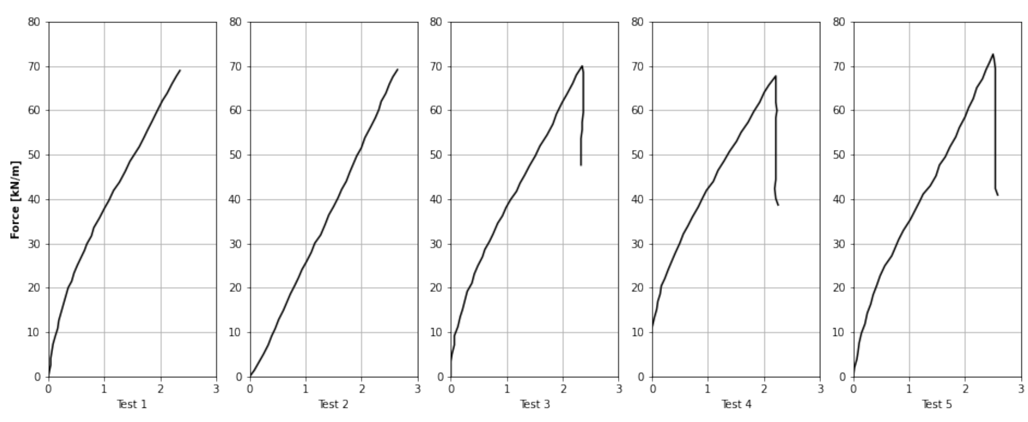



Figure 3.8: Force [kN/m] vs strain [%] for Fortrac R 50/50-40 B basalt geogrid protected with PU-foam in MD

Table 3.9: Statistics from wide width tensile test on Fortrac R 50/50-40 B basalt geogrid protected with PU-foam in MD

| n=5 | Fm [N] | Fm [kN/m] | Am [%] | F0 [kN/m] | F1 [kN/m] | F2 [kN/m] | $\epsilon 1$ [%] | v-test [%/min] |
|---|---|---|---|---|---|---|---|---|
| $\bar{x}$ | 3208 | 69,73 | 2,26 | 24,48 | 37,67 | 49,65 | 1,09 | 21,86 |
| s | 89 | 1,94 | 0,18 | 6,90 | 6,20 | 5,36 | 0,24 | 1,14 |
| V | 2,79 | 2,79 | 7,97 | 28,17 | 16,45 | 10,79 | 21,95 | 5,20 |

The obtained tensile strengths and strains at failure from the tests performed on Fortrac with different protections are shown in Figure 3.9 and Table 3.10.

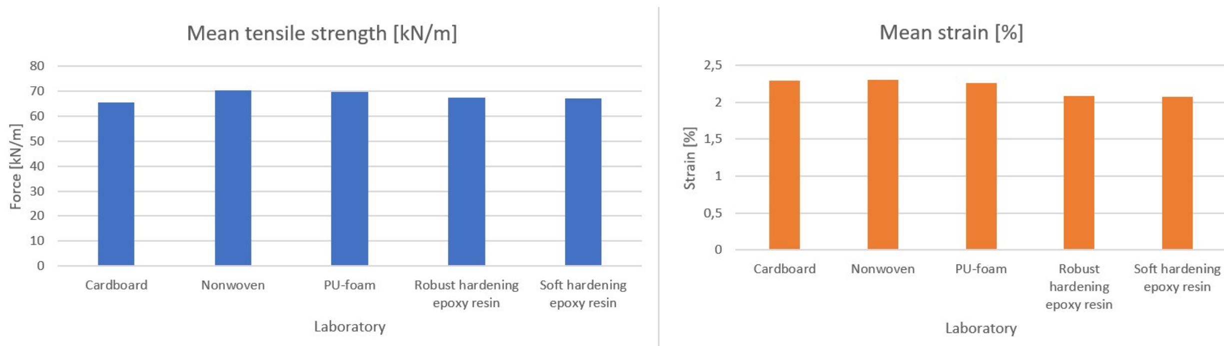



Figure 3.9: Comparison of different protections on Fortrac R 50/50-40 B

Table 3.10: Summary of test results on Fortrac R 50/50-40 B basalt geogrid with different protections

| Protection | Mean tensile strength [kN/m] | Mean strain [%] |
|---|---|---|
| Cardboard | 65,35 | 2,29 |
| Nonwoven | 70,50 | 2,31 |
| PU-foam | 69,73 | 2,26 |
| Robust hardening epoxy resin | 67,42 | 2,08 |
| Soft hardening epoxy resin | 67,03 | 2,07 |

**Evaluation of performance**

The same material has been put through the same test with five different materials in the clamping area to try to avoid slippage. The products used were cardboard, nonwovens, PU-foam, solid hardening epoxy resin, and soft hardening epoxy resin. All results are given in Figures 3.4 to 3.9 and in Tables 3.5 to 3.10.

The mean value for the maximum tensile force varies between 65,4 kN/m and 70,5 kN/m. The lowest value was obtained by using cardboard while the highest value was obtained by using nonwovens in the clamping area. The standard deviation was somewhat lower for the tests using cardboard, but not too much.

The maximum strain was found to be 2,1 % for the tests with epoxy in the clamping area and 2,3 % for the other tests. The standard deviation on the tests was small. The value is low, but as expected. The tests clearly show that the material is very brittle.

These tests indicate that it is favorable to protect the clamping area with nonwovens to obtain the best results.

### 3.2.2 Creep rupture behaviour on Fortrac R 50/50-40 B basalt geogrid

KIWA have performed tests to determine the creep rupture behavior of Fortrac R 50/50-40 B basalt geogrid according to ISO 13431 (ISO 1999). In the test, the specimens are loaded with a constant static force. The elongation of the specimen is recorded throughout the test. The duration should be 1000 h or until rupture. While the wide width tensile test deals with short time failure, this test deals with failure over time due to creep. Nonwoven, PU-foam and robust hardening epoxy resin have been applied in the clamping area to avoid slippage.

Table 3.11: Test data for Fortrac R 50/50-40 B basalt geogrid in creep rupture tests

| **Test data** | |
|---:|---|
| Material | Fortrac R 50/50-40 B |
| Test norm | ISO 13431:1999-11 |
| Date | 11.04.2012 and 15.11.2012 |
| Test direction | MD |
| Specimen width | 1 strand |
| Test apparatus (Short time < 100 h) | Zwick Z250 / Zwick Z050 /Instron 5567 |
| Test apparatus (Long time > 100 h) | Vertical steel frame - load is applied by lever arm |
| Clamping system | Hydraulic clamps / roller clamps |
| | Note: Clamping area of grid protected with nonwoven, |
| | PU-foam or robust hardening epoxy resin |
| Climate | 23 ° C / 45 % relative humidity |
| Method for tensile strength | ISO 10319:2008-10 |
| Ultimate tensile strength UTS | 70,5 kN/m (3243 N at specimen width of 1 strand) |
| Strain at max load | 2,3 % |

**Results**

Specimens protected with nonwoven tested 11.04.2012

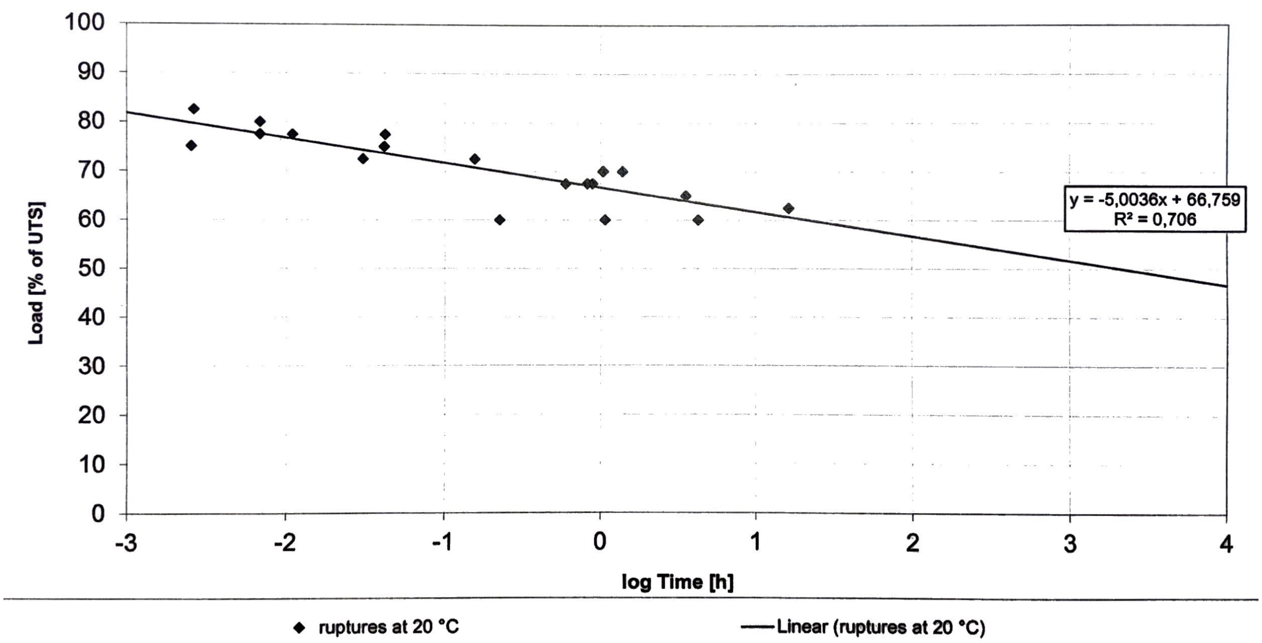



Figure 3.10: Load [% of UTS] vs log time [h] for Fortrac R 50/50-40 B basalt geogrid protected with nonwoven in MD

Specimens protected with PU-foam tested 15.11.2012

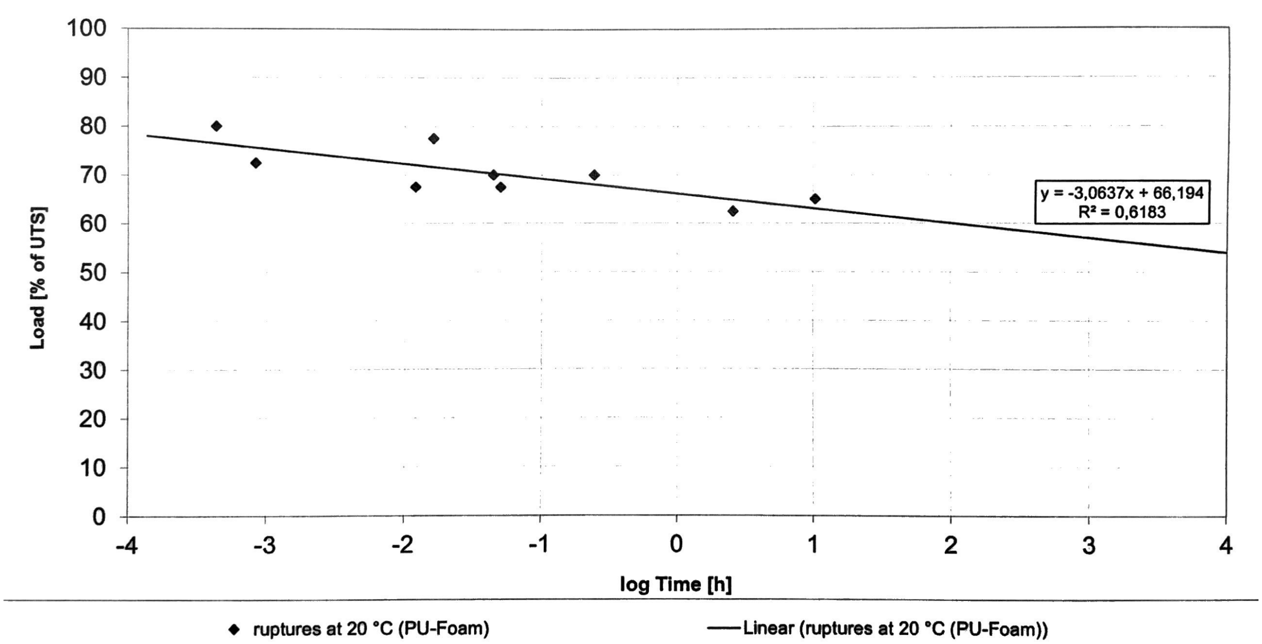



Figure 3.11: Load [% of UTS] vs log time [h] for Fortrac R 50/50-40 B basalt geogrid protected with PU-foam in MD

Specimens protected with robust hardening epoxy resin tested 15.11.2012

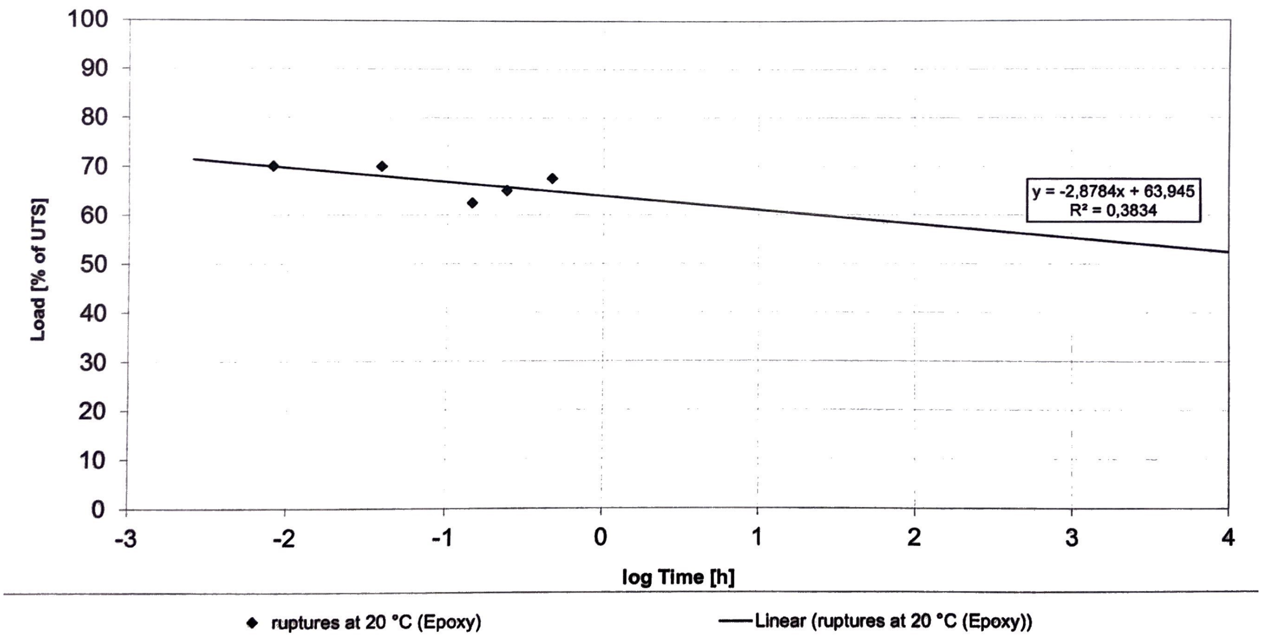



Figure 3.12: Load [% of UTS] vs log time [h] for Fortrac R 50/50-40 B basalt geogrid protected with robust hardening epoxy resin in MD

**Evaluation of performance**

The three tests have been protected with nonwovens, PU-foam or robust hardening epoxy resin. The tests performed with nonwovens have the most data points, the ones with PU-foam a few less and the ones with epoxy has the fewest. A linear regression line has been made based on the data points.

The diagrams give information on how long time it would take to reach creep rupture when the load is at a specific percentage of the ultimate tensile strength. The longer it takes until this happens, the better. The linear regression line is in the form $y = ax + b$, where $y$ is the load in percent of UTS, $a$ is the slope of the curve and $b$ is the constant. $a$ is negative for all tests. When $a$ is close to zero and $b$ is close to 100, the better properties the material has. It should be noted that the time scale is logarithmic.

The best results seem to be obtained from the test where PU-foam has been used for protection.

### 3.2.3 Long time creep behaviour of Fortrac R 50/50-40 B in MD

A long time creep test has been performed on the Fortrac R 50/50-40 B. It has been running for nearly seven years or 58 880 hours and was still ongoing when these results were shared.

**Results**

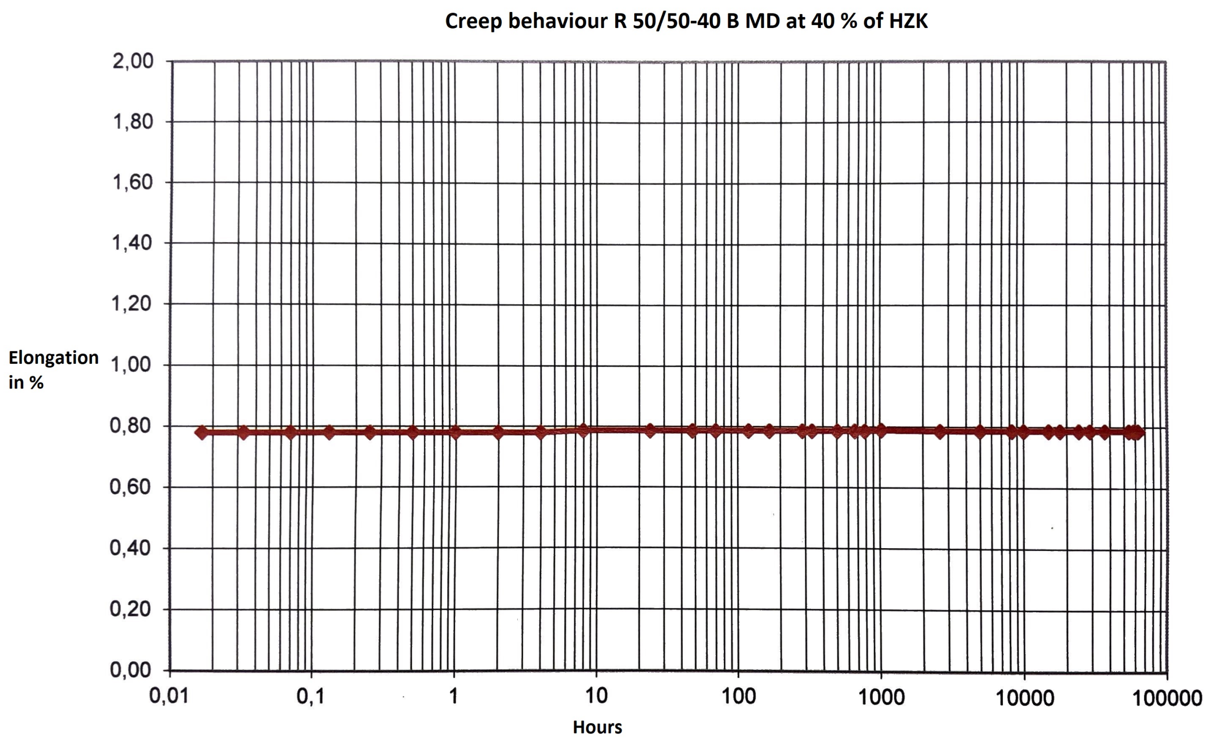



Figure 3.13: Elongation [%] vs time [h] for Fortrac R 50/50-40 B in MD

**Evaluation of performance**

This test shows no sign at all of creeping. The plotted line is almost linear and close to horizontal. This indicates that the product and the material have very good creep properties. For some applications, this may be of great importance.

### 3.2.4 Resistance to weathering of Basalt product A

Basalt product A has been put through weathering testing at KIWA's laboratory. Weathering is a known problem for several polymer materials. Weathering may be caused by UV radiation, alkalis, fungus, vermin, insects, fuel, detergents, or others. In this test, the QUV has been used. It is an accelerated weathering tester that simulates the work of sunlight, rain and dew over months or years in a compressed period in the lab. It uses fluorescent UV lamps that work in the UVA, UVB and UVC portions of the spectrum. In addition, dew and rain is simulated with condensing humidity and water spray.

After running the weathering test for 424 hours the specimens have been tensile tested and compared to reference specimens.

Table 3.12: Test data for determination of the resistance to weathering of Basalt product A

| **Test data** | |
|---|---|
| Material | Basalt product A |
| Test norm | ISO 12224:2000-11 |
| Date | 23.02.2015 |
| Weathering tester | UV tester type QUV/spray |
| Luminous intensity | 50 MJ/m$^2$ |
| Test cycle | 5 h dry cycle (50 ± 3 °C) |
| | 1 h wet cycle (25 ± 3 °C black sensor panel) |
| Number of cycles | 71 |
| Test direction | MD and CMD |
| Size of specimen in MD | 2 strands x 300 mm |
| Size of specimen in MD | 2 strands x 300 mm |
| Duration | 424 h (27.01.15 to 14.02.15) |
| Test method | ISO 10319:2008-10 |
| Evaluation | ISO 12226:2012-03 |

**Results**

Table 3.13: Results from determination of the resistance to weathering of Basalt product A in MD

| **Specimen number** | **Tensile strength [N]** | | **Strain at max force [%]** | |
|---|---|---|---|---|
| | **Reference specimen** | **Exposed specimen** | **Reference specimen** | **Exposed specimen** |
| Mean $\bar{x}$ | 5438 | 5409 | 2,2 | 2,1 |
| Standard deviation s | 440,4 | 254,3 | 0,32 | 0,10 |
| Coefficient of variation V [%] | 8,1 | 4,7 | 14,8 | 4,9 |
| Residual strength / strain [%] | 99,5 | | 99,1 | |

Table 3.14: Results from determination of the resistance to weathering of Basalt product A in CMD

| **Specimen number** | **Tensile strength [N]** | | **Strain at max force [%]** | |
|---|---|---|---|---|
| | **Reference specimen** | **Exposed specimen** | **Reference specimen** | **Exposed specimen** |
| Mean $\bar{x}$ | 5229 | 5096 | 2,0 | 2,0 |
| Standard deviation s | 109,2 | 253,9 | 0,11 | 0,05 |
| Coefficient of variation V [%] | 2,1 | 5,0 | 5,4 | 2,4 |
| Residual strength / strain [%] | 97,5 | | 101,1 | |

**Evaluation of performance**

Specimens have been tested in both machine direction and cross machine direction. In MD the residual strength was found to be 99,5 % while the residual strain was 99,1 %. In other words, the test specimens lost nearly no strength despite being put through the weathering test. In cross machine direction the residual strength was 97,5 % while the residual strain was 101,1 %. The loss of strength was somewhat bigger than it was in the machine direction. The residual strain at 101,1 % means that the exposed specimen obtained a higher strain value after weathering. Most likely this increase is caused by coincidences.

The tests show that the material is not significantly affected by weathering. The changes in strength or strain are very low. This seems reasonable. In nature, the material is exposed to all kinds of environments. It does not weather considerably.

### 3.2.5 Microbiological resistance by a soil burial test on Basalt product A

The exposed specimens have been burried in a microbiologically active soil consisting of the product ED73. ED73 is a nutrient-rich, fertilized peat-clay soil. The specimens have been in this environment for one month before they were tensile tested and compared to the reference specimens.

Table 3.15: Test data for determination of the microbiological resistance by a soil burial test on Basalt product A

| **Test data** | |
|---|---|
| Material | Basalt product A |
| Test norm | ISO 12225:2000-12 |
| Date | 05.06.2015 |
| Test direction | MD and CMD |
| Size of specimen | 2 strands x 300 mm |
| Number of specimen | 5 reference (ref.) specimen |
| | 5 exposed (exp.) specimen |
| Incubation | Climatised room |
| Test soil | Acclimatised new soil; microbiological active |
| | (1 month at about 28 °C and 97 ± 2 % relative humidity) consisting of: |
| | "Classic ED73" |
| Test climate | 26 ± 1 °C / 95 ± 5 % relative humidity |
| Saturation moisture content | 60 % SMC |
| Chemical fertilizers for soil | Ammonium nitrate, dipotassium-hydrogen phosphat |
| Cotton fabric for control | Untreated woven cotton fabric (250 g/m$^2$) |
| Container for soil | Plastic container without lid (46,0 x 46,0 x 16,0 cm) |
| Duration | 16 weeks (03.02.2015 to 01.06.2015) |
| Test method | In accordance with ISO 10319 |
| Evaluation | ISO 12226:2000-12 |

**Results**

Table 3.16: Results from determination of the microbiological resistance by a soil burial test on Basalt product A in MD

| **Specimen number** | **Tensile strength [N]** | | **Strain at max force [%]** | |
|---|---|---|---|---|
| | **Reference specimen** | **Exposed specimen** | **Reference specimen** | **Exposed specimen** |
| Mean $\bar{x}$ | 5217 | 5792 | 2,25 | 2,36 |
| Standard deviation s | 260 | 357 | 0,19 | 0,11 |
| Coefficient of variation V [%] | 5,0 | 6,2 | 8,6 | 4,9 |
| Residual strength / strain [%] | 111,0 | | 105,2 | |

Table 3.17: Results from determination of the microbiological resistance by a soil burial test on Basalt product A in CMD

| **Specimen number** | **Tensile strength [N]** | | **Strain at max force [%]** | |
|---|---|---|---|---|
| | **Reference specimen** | **Exposed specimen** | **Reference specimen** | **Exposed specimen** |
| Mean $\bar{x}$ | 4927 | 4928 | 2,28 | 2,13 |
| Standard deviation s | 175 | 277 | 0,28 | 0,17 |
| Coefficient of variation V [%] | 3,6 | 5,6 | 12,4 | 7,8 |
| Residual strength / strain [%] | 100,0 | | 93,2 | |

**Evaluation of performance**

In MD the residual strength was 111 %, meaning that the product obtained a higher mean tensile strength after being burried for one month. The same goes for the strain where the residual value was 105,2 %. Both properties have increased. It is uncertain what this is due to. It may be due to substances in the soil that react with the product and strengthen it. Another explanation, and probably the most likely one, may be that it is due to irregularities in the product and that it is due to coincidences. In CMD the residual tensile strength remains unchanged. The residual strain is somewhat lower.

The overall impression from the tests is that the material is well suited to be placed in a microbiologically active environment.

# Chapter 4

# Products tested

One geotextile and one geogrid have been tested throughout the thesis.The geotextile is made of 100 % basalt and supplied by EB Marine AS whereas the geogrid is made of basalt and a polymer with a coating, and is supplied by ReforceTech AS.

Through Arnstein Watn a connection to the Stavanger-based company EB Marine was made. Martin Napierala has been the contact person at EB Marine. The contact with ReforceTech was established through a family friend who knew Len Miller. Both companies provided their products for testing.

## 4.1 Geotextile from EB Marine

EB Marine is first and foremost an underwater contractor. Their main customers are the public sector, contractors, shipping agents, and consultants. They specialize in diving missions. Some of the work they do for the construction industry is related to foundation work, dredging, formwork, casting, drilling, and erosion protection work. In the erosion protection work, they use specially adapted concrete mattresses, pillows, silt curtains, separation cloths, and more. They are using and have used geotextiles a lot.

Napierala informed Watn of their basalt geotextile in connection with an inquiry they had received for a project in Germany. The knowledge of the product properties was limited. The product data sheet shown in Table 4.1 gives basic data but no mechanical properties for the products. Napierala had no further data than the product data shown in the table. A product sample was sent to be tested. It has been put through various standardized tests. The product will be referred to as EB geotextile.

Table 4.1: Product data for EB geotextile

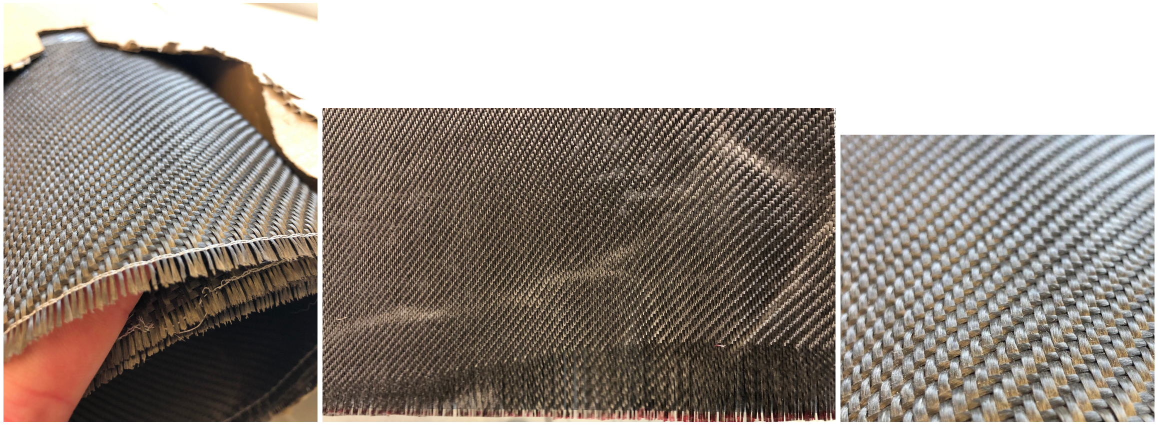
| **Product data** | |
|---|---|
| Name | Basalt fiber woven textile 630 |
| Material | 100 % basalt |
| Production technique | Woven |
| Filament density | 2,67 $g/dm^3$ |
| Width | 1580 mm (ISO 5025:1997) |
| Length | Max. 500 m |
| Thickness | 0,36 mm (ISO 4603:1993) |
| Surface weight | 630 $g/m^2$ (ISO 3374:2000) |
| Weight per roll | 500 kg |
| Melting point | 1350 °C |
| UV stability | > 7 (ISO 105-B02) |

In Figure 4.1 five pictures of the product are shown. The product recieved for testing was delivered in a roll packed in cardboard. When unpacking the geotextile footmarks were registered on the product. This indicates that someone has stepped on it. No damage was detected visually. This is unfortunate for the testing but has in all probability not affected the results significantly.

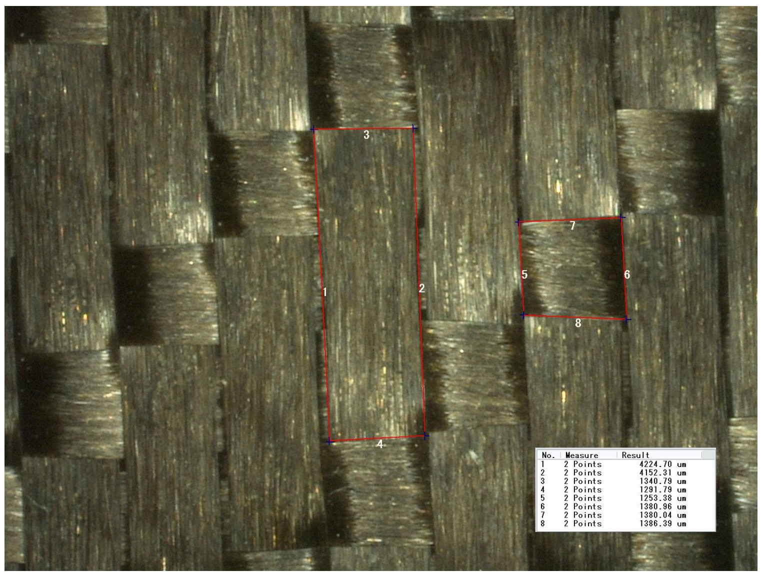
In the preparation of the test specimens, it was discovered that the threads did not go straight through the entire test piece but moved in irregular waves. This can be seen in Figure 4.1 (b). When the specimens are prepared for the tensile test, the outer threads are removed. Now that the threads do not go straight, this could affect the geometry of the test piece and may be a weakness.

The product has been studied under a microscope. The weaving technique appears to be a twill weave, apparently a 3/1 twill weave. The weft thread is passed over one or more warp threads and then under two or more warp threads in a twill weave. This makes the characteristic diagonal pattern. It is supposed to be softer than plain weaves.

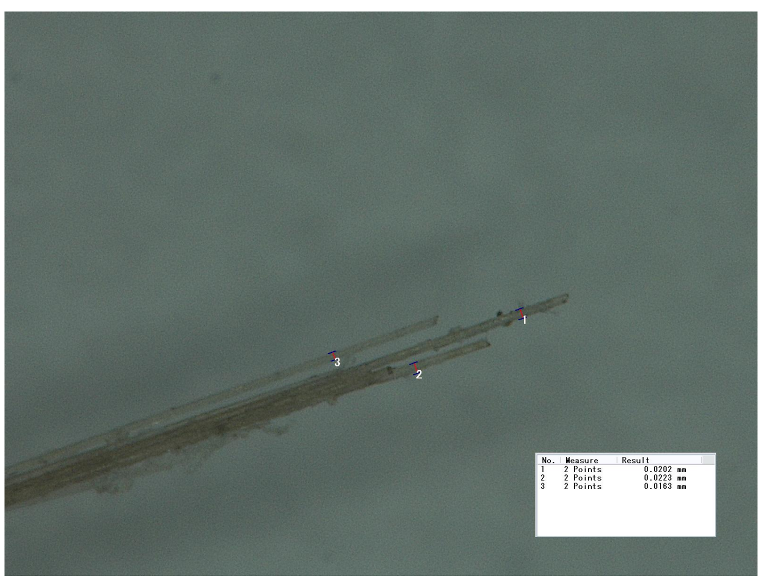
The size of the threads has been studied in the microscope as well and is shown in Figure 4.1 (e). On average they were found to be 0,02 mm corresponding to 20 μm. In the literature study it was found that fibers with diameter less than 3,5 μm could be harmful. It was also found that the mean value of the fragment fiber diameter is the same as the diameter of the undamaged fiber. If this is the case, the fibers from this product should not be harmful to health.



(a) Product rolled up (b) Weakness in production (c) Weaving pattern




(d) Weave details




(e) Fiber details

Figure 4.1: EB geotextile

## 4.2 Geogrid from ReforceTech

ReforceTech mainly work with the reinforcement of concrete. They specialize in the developement and production of basalt and glass fiber products with their main facility in Røyken, Norway. MiniBars and BasBars are produced from basalt and/or glass fibers. The MiniBars are designed to be secondary and/or primary reinforcement. It is a macrofiber that disperses into the concrete matrix and has the same specific gravity as the concrete. BasBars are made to replace primary steel reinforcement. It is a composite rebar where basalt fibers are embedded in a vinyl ester resin to make reinforcement bars in various sizes.

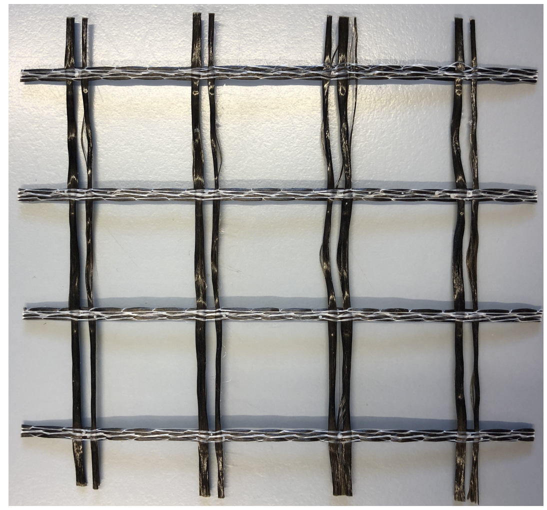
GeoGrid is another product in their portfolio. It is a fiber-reinforced plastic (FRP) material based on basalt and protected with an alkali-resistant coating. The load is carried by the basalt fibers while plastic threads are used to keep the basalt fibers in place. ReforceTech state that the product is suitable for reinforcing roads, railways and concrete applications. According to Miller, ReforceTech does not produce nor sell much of this product. In the product data sheet, mechanical properties are not stated. The product data sheet describes the product along with its' claimed benefits. The benefits stated are:

- Higher mechanical strength and modulus, more resistive to chemical aggressive environments than E-glass mesh.
- The melting point of basalt fibers is 1450°C.
- Typical paving temperatures will not cause any loss application temperature than for synthetic material. That is especially important for north regions.
- Lower elongation before break rupture than for synthetic material.
- Easily milled using typical milling equipment.
- Does not stretch and pull as polymer meshes.
- No special equipment is required to install the reinforcement.
- Basalt mesh is environment friendly and based on naturally occurring material that is found worldwide.
- Specially developed coating provides good adhesion with concrete to improve tensile strength and increase impact resistance.
- High mechanical strength and modulus.
- High resistance to chemical aggressive environment and in particular high alkali resistance will not allow appearance of rust or corrode.
- Minimizes crack width and spread.

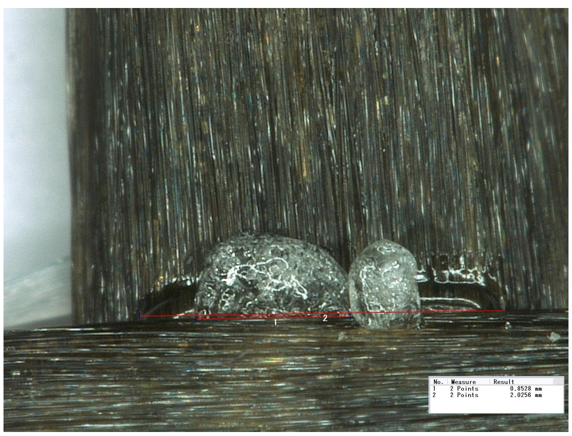
Figure 4.2 shows five pictures of the product. Figure 4.2 (b) shows a specimen where the MD is going from top to bottom. The opening size between the threads is approximately 30 x 30 mm. In MD the product has three strands held together by a polymeric thread. This can be seen in Figure 4.2 (e). Two parallel strands make up the cross machine direction. In the crossings between the longitudinal threads and the perpendicular ones, the product is held together with the same polymeric thread.

In Figure 4.2 (c) and (d) some kind of contamination is visible. Figure 4.2 (c) is from a crossing between the two orthogonal directions. Two bubbles are visible as well as a stripe. The diameter of the biggest bubble is approximately 0,9 mm whereas the length of the stripe is approximately 2,0 mm. This contamination is most likely due to glue or the polymeric thread being melted in a heating process.

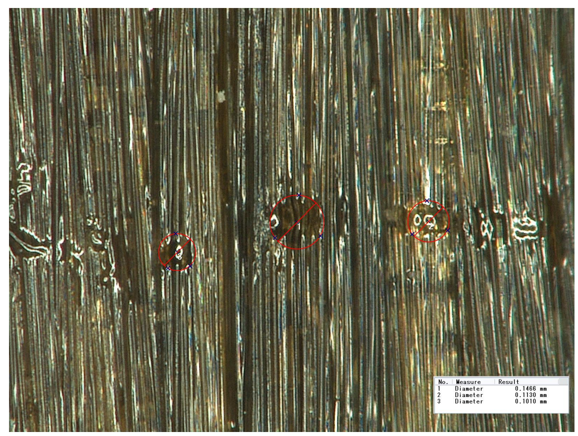
(a) Product rolled up



(b) Specimen



(c) Production detail



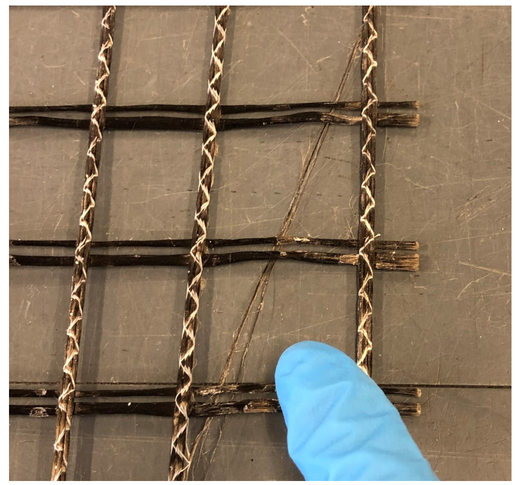
(d) Production detail

(e) Fibers detail

Figure 4.2: RT geogrid

During the preparation of the specimens, some production defects were discovered. In some places, the threads were not stretched out but bent out, as shown in Figure 4.3 (a). This was discovered in CMD. These threads will not contribute to absorbing tensile forces. However, this area was avoided when preparing specimens. In other places, threads went from one strand to another. It was also observed that the dimensions of the opening size between the threads were not always 30 x 30 mm as can be seen in Figure 4.3 (b).

(a) Threads bent out



(b) Threads going from one strand to another

Figure 4.3: Defects from production of RT geogrid

# Chapter 5

# Mechanical damage under repeated loading

## 5.1 The standard

The index test procedure for the evaluation of mechanical damage under repeated loading caused by granular material is a laboratory test method constructed to determine how much a geo-product will deteriorate during installation (ISO 2019a). The testing is also done in the field on a full scale. It should be noted that the results obtained from the laboratory and the field may differ a lot.

### Principle

The purpose of the test is to simulate the load that the product is exposed to during installation in the field. This will in many cases be repetitive loads from heavy construction machines. The specimen is put in the middle of a standard granular material and put under a dynamic load for a given period. Thereafter the specimen is controlled for visual damages. To measure the change in mechanical properties the specimen is subjected to a mechanical test, typically wide width tensile tests according to ISO (2015).

### Apparatus

The test apparatus is not very complicated but the test is performed rather rarely. As far as the author is concerned this equipment is not publicly available in Norway. Therefore the tests have been performed at KIWA's laboratories in Greven, Germany.

The system consists of a test container, aggregate, a loading plate, and a compression machine.

The test container should have dimensions of 300 x 300 mm internal in the plane as a minimum. It should consist of an upper part and a lower part, each 75 mm deep. The lower part should be mounted on a rigid base that does not deflect more than 1 mm during loading. The container used in the test performed had openings on two of the sides for easy mounting of the specimen. To avoid the aggregates from falling out from these openings a sheet of paper was folded and put against the opening.

The aggregate mentioned is a standard granular material. It should be a sintered aluminum oxide with a grain size between 5 and 10 mm. None of the grains should be smaller than 5 nor greater than 10 mm. The material used in the performed test was named NK6-8MM referring to a grain size between 6 and 8 mm.

To compact the material and apply the load, a loading plate and a compression machine are required. The loading plate should be of dimensions 100 x 200 mm. It should be made of steel or aluminium and should be able to transfer the loads to the aggregate without deflection. The compression machine should be able to produce a sinusoidal pressure of between 10 ± 1 kPa and 500 ± 10 kPa on the loading plate with a frequency of 1 Hz.

A principle sketch of the test setup, as well as the used test setup, is shown in Figure 5.1 and 5.2.

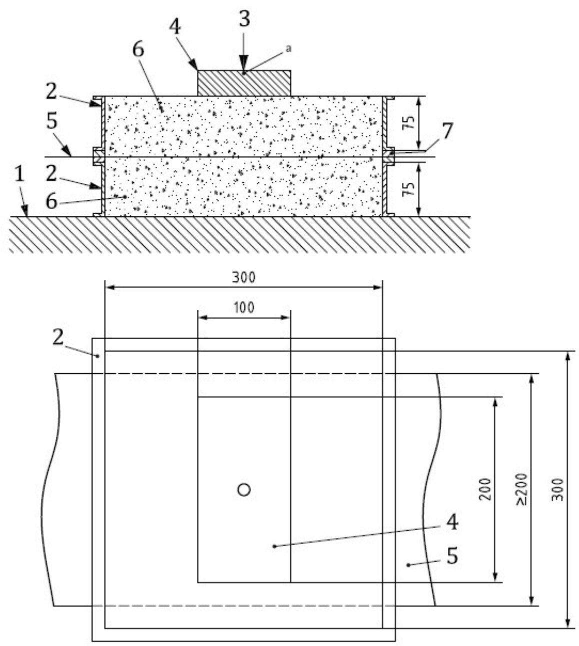



Figure 5.1: Principal sketch for damage testing (ISO 2019a)

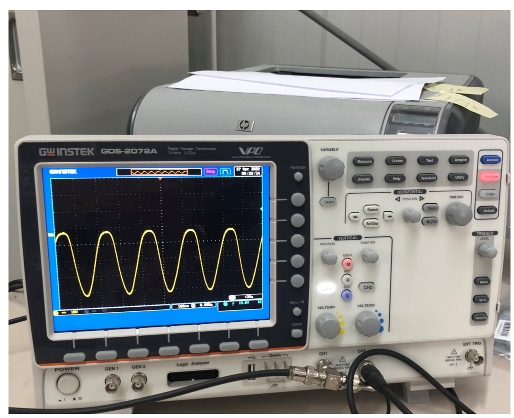
The numbers in Figure 5.1 represents the following:

1. rigid base support
2. rigid metal box
3. applied load
4. loading plate
5. test specimen
6. aggregate
7. shims

(a) System with loading plate, test container and aggregate in the lower part


(b) EB geotextile mounted in the rig

(c) RT geogrid after testing




(d) Sinusoidal load

Figure 5.2: Damage test setup

## Test specimens

The specimens need to be cut to fit the wide width tensile test after damage testing. According to the standard five specimens of at least 2,0 m length and 0,2 m width in MD should be cut. Each specimen is then cut into two specimens of at least 1,0 m in length and 0,2 m in width. One is supposed to be a reference specimen while the other is to be used in the damage procedure before it is put in the tensile test.

### Test procedure

The lower part of the test container is filled with granular material. The material is compacted in two steps for two equal layers. A pressure of 200 ± 2 kPa is applied for 60 s. This step only needs to be done once.

A test specimen is then placed across the lower part, centered and with the free edges equally spaced from each side. The upper part of the container is then mounted. In the performed test two sheets of paper were installed in the two openings as mentioned, before the upper part was gently filled with the granular material.

Before the sinusoidal load is applied a preload of 5 ± 1 kPa is applied. Thereafter the cyclic load is started. It should produce a load between 10 ± 1 kPa minimum and 500 ± 10 kPa maximum at a frequency of 1 Hz for 200 loading cycles. The area of the test container is fixed on a platform and not moving while the loading plate is pulsating. Therefore the pressure should be measured from the loading plate.

The specimen is then removed and inspected visually. The procedure is repeated for all specimens. Both the reference specimens and the damaged specimens are then tested according to ISO 10319.

### Calculations

The test aims to determine the change in mechanical properties. The change in properties should be calculated as a retained value in percent:

$$\Delta R = 100 \cdot (\frac{R_d}{R_0})$$

where

$\Delta$ R = retained value in percent,

$R_d$ = mean value for the damaged specimen,

$R_0$ = mean value for the reference specimen.

### Notes

It should be noted that some producers of geo-related products are dissatisfied with this test. This is especially the case for producers of geogrids. The aggregates tend to hit the nodes and consequently damage the specimen leading to poor results. According to Watn this is mainly a concern for producers of geogrids and not geotextiles as they do not suffer as much from this.

## 5.2 Testing at KIWA in Greven, Germany

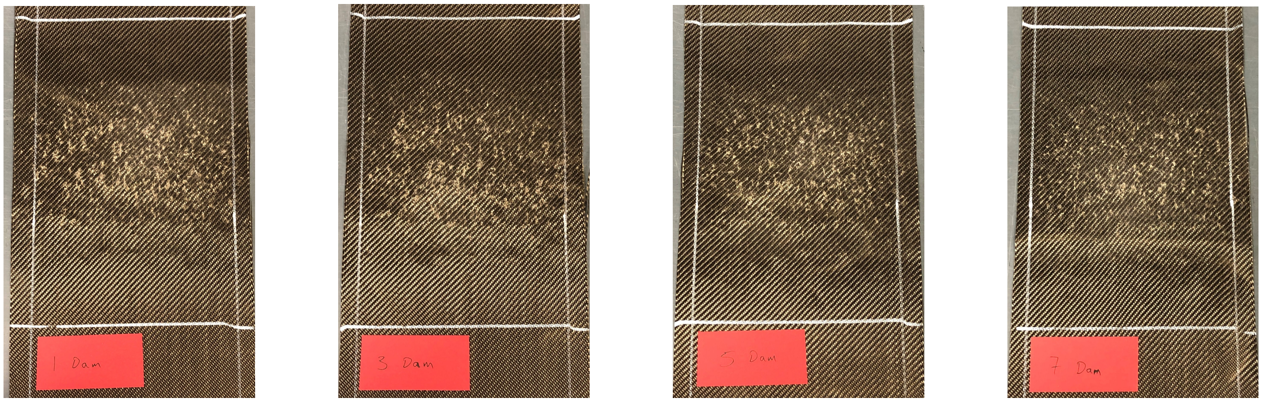
The tests were performed for both the EB geotextile and RT geogrid at KIWA's test facilities in Greven, Germany. The specimens were first put through damage testing (ISO 10722). Later the reference specimens and damaged specimens were put through the tensile test (ISO 10319).

### 5.2.1 EB geotextile


Figure 5.3: Preparation of test specimens on EB geotextile

As shown in Figure 5.3 the amount of available sample material was less than desired. The specimens could therefore not be cut in two meters lengths as proposed by the standard. There was not enough material to prepare five specimens for damage testing and five specimens for reference. The solution was to make eight test specimens. Four for damage testing and four for reference. They were cut as shown in the figure. Six pieces were cut side by side and numbered from left starting from number one. Pieces seven and eight were taken from the part of the textile at the top right of the figure. Test pieces one, three, five and seven were put in the damage test. Test pieces two, four, six and eight were reference specimens.

After following the procedure for damage testing on specimens one, three, five and seven they were inspected visually. Clear damage was observed on all test pieces. The aggregate had punctured the fabric in several places. Pictures of the test specimens are shown in Figure 5.4. The white lines on the specimens indicate the area that has been in contact with the aggregate.




(a) Specimen 1 (b) Specimen 3 (c) Specimen 5 (d) Specimen 7

Figure 5.4: EB geotextile specimens after damage testing

Fibers were split where this had happened. Pictures taken with the use of a microscope show this in Figure 5.5.

(a) Middle fiber from left to right broken (b) Specimen penetrated and fibers broken in the lower part of the picture (c) Broken fibers in the middle of the picture

Figure 5.5: Broken fibers from EB geotextile after damage testing

Results from tensile testing and the retained values are presented in Chapter 6.4.1.

### 5.2.2 RT geogrid

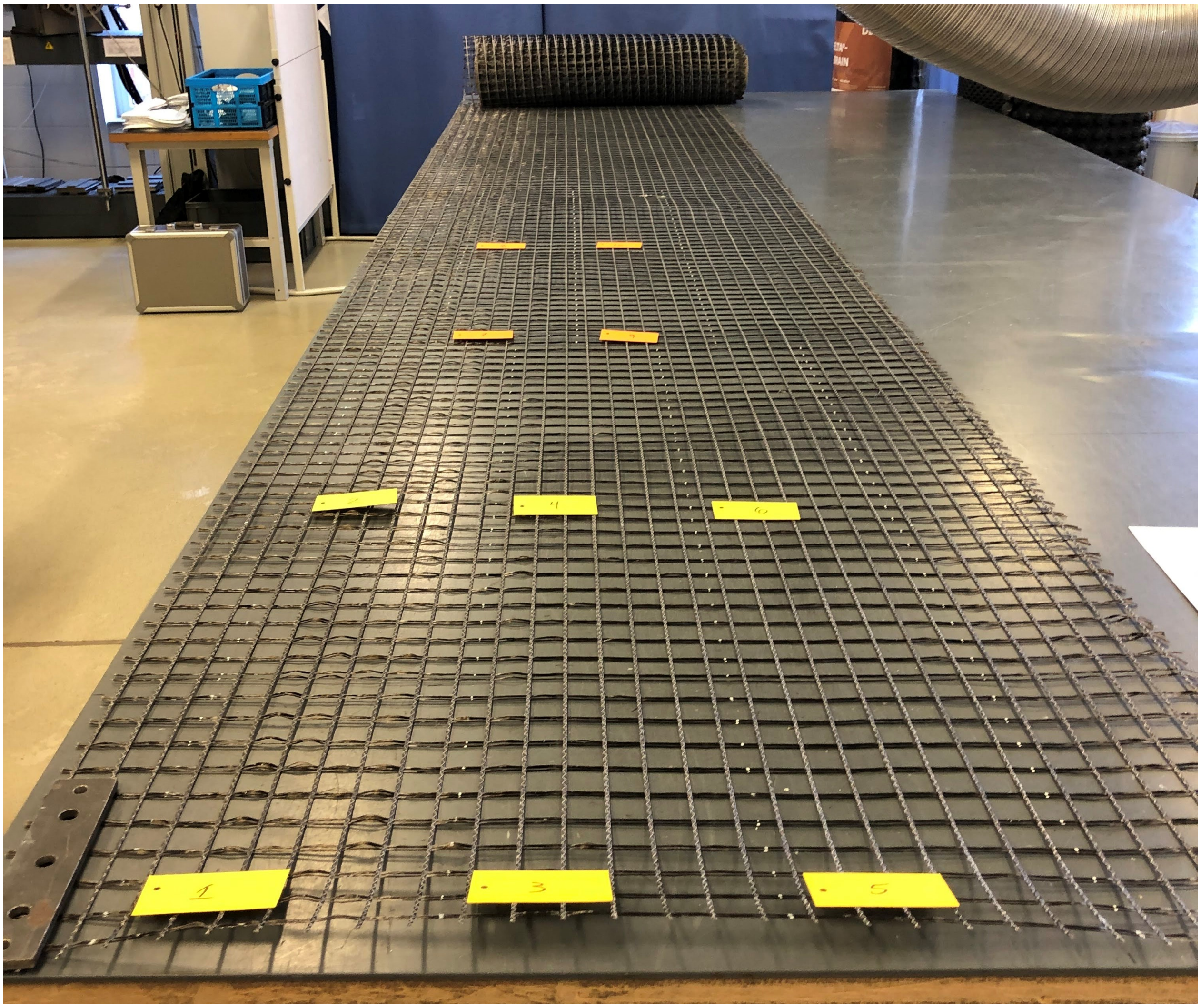
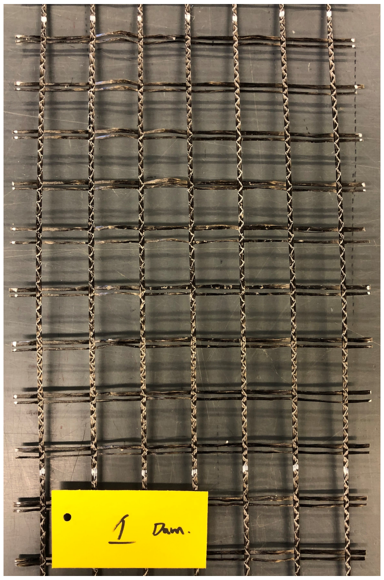


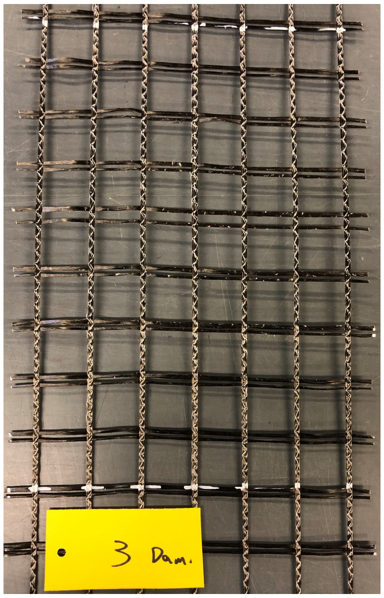
Figure 5.6: Preparation of test specimens on RT geogrid

The amount of sample material was significantly more for the RT geogrid. With this product, the specimens could be prepared according to the standard with five specimens for damage testing and five specimens for reference. The specimens were numbered from one to ten. Pieces one and two, three and four, and five and six were prepared on the same strip and then cut in two. They are shown in the lower part of Figure 5.6. Further towards the roll specimens seven and eight, and nine and ten were cut in the same way. Specimens numbered with odd numbers were put through the damage test while specimens with even numbers were reference pieces.

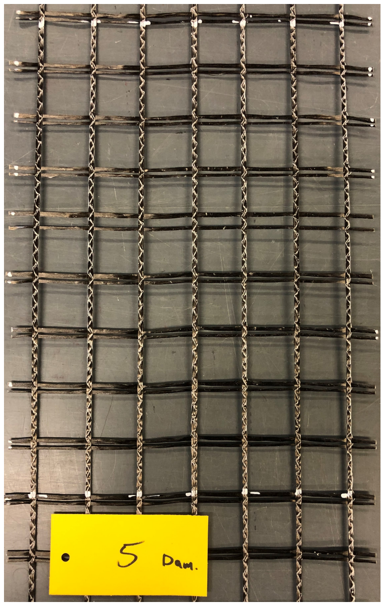
The specimens were tested according to the procedure. The damages on the specimens were not as obvious as for the EB geotextile. Marks from the aggregate were visible in some places. No punctures or serious damages were observed. The coating on the product may have contributed to this. The specimens after damage testing are shown in Figure 5.7 and 5.8.



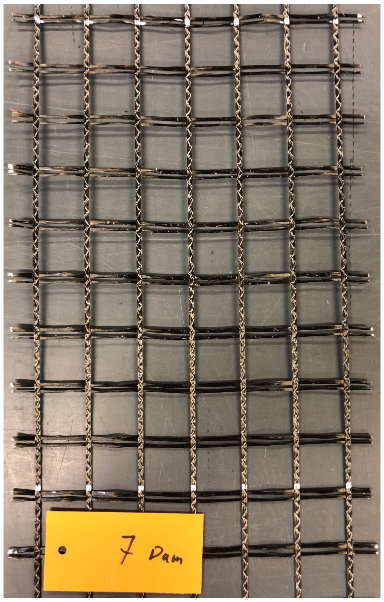

(a) Specimen 1



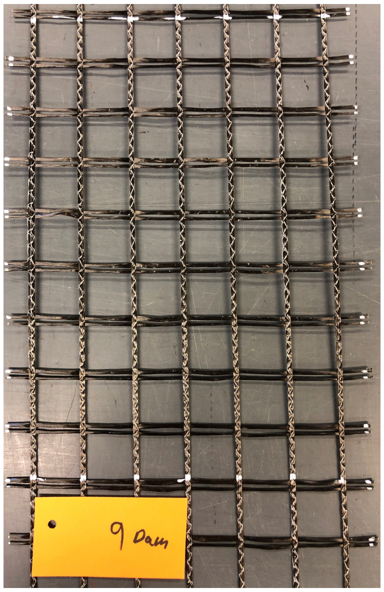

(b) Specimen 3




(c) Specimen 5




(d) Specimen 7




(e) Specimen 9

Figure 5.7: RT geogrid specimens after damage testing

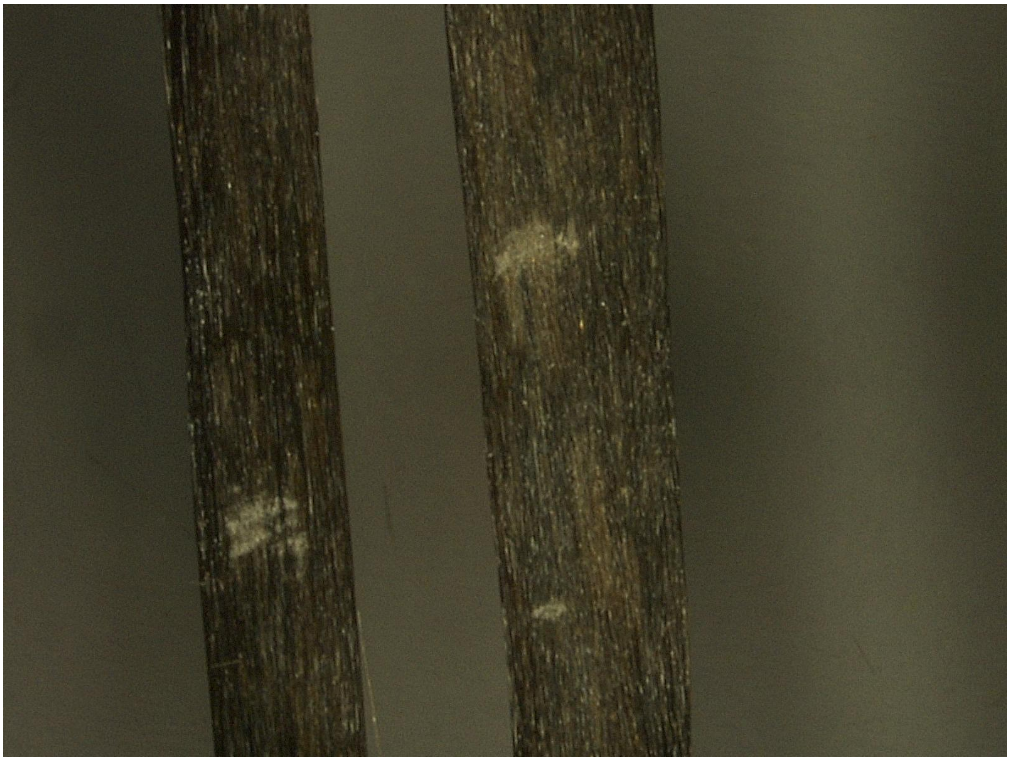


Figure 5.8: Marks from the aggregate on RT geogrid

Results from tensile testing and the retained values are presented in Chapter 6.4.2.

# Chapter 6

# Wide width tensile tests

## 6.1 The standard

Wide width tensile tests are used to identify the tensile properties of a geosynthetic. A geosynthetic may be made out of polymers, glass or metals according to the standard. Even though none of these material classes are fitting for basalt the products are tested according to this standard.

Most of this section is more or less taken from ISO 10319 (ISO 2015). As the standard plays an important role in the work carried out, it is chosen to include most of it in this thesis.

### Principle

The test aims to find the tensile properties of the specimen. To do this, a specimen is installed in the test rig. The specimen should be 200 mm wide and 100 mm long. The width is greater than the length to avoid contraction under load in the gauge length area. A set of clamps is used to hold the specimen in place. Extensometers are mounted on the test rig and on the specimen. During testing, the specimen is exposed to a longitudinal force that ensures a constant displacement speed until rupture occurs.

### Apparatus

The machine should have a constant rate of extension, so that the strain-rate is uniform with time. The clamps or jaws on the machine should be wide enough to hold the entire width of the specimen. In addition they should minimize slippage or damage of the specimen. Compressive jaws are preferred but capstan grips may be used. The principle of these are shown in Figure 6.1, where friction by lateral pressure is shown to the left and capstan or roller clamps are shown to the right. They should comply with the standard ISO 7500-1 class 2 or better. This is where the test machine available at NTNU comes to short.

Figure 6.1: Principal sketch of grips for tensile testing (ISO 2015)

## Test specimens

### Woven geotextiles

The nominal width of the specimen should be 200 ± 1 mm. This is obtained by cutting it approximately 220 mm wide and then removing an equal number of threads from each side until the specimen gets the correct width.

### Geogrids with two axes

Geogrids should also be prepared to a width of 200 mm. They should be cut at least 10 mm from any node according to the standard.

## Test procedure

The length from clamp to clamp should be 100 ± 3 mm at the start of the test. As different products have different strengths, the load cell should be chosen according to the estimated forces. In this way the capacity can be measured to an accuracy of 10 N, which is stated in the standard.

When the expected strain of the specimen is more than 5 % the strain rate should be 20 ± 5 % per minute. When the expected strain is less than 5 % the specimen should break in 30 ± 5 s.

The specimen is installed in the rig so that the specimen length and the applied force are parallel. An extensometer is installed on the specimen. It should be mounted with fixed reference points 60 mm apart, which means 30 mm on each side of the symmetry centre. This is shown for a typical geogrid with two axes in Figure 6.2. In the figure, mark 1 shows the gauge marks for elongation measurement, mark 2 shows the number of load bearing elements $n_s$ and mark 3 shows a cut in exterior elements before loading.

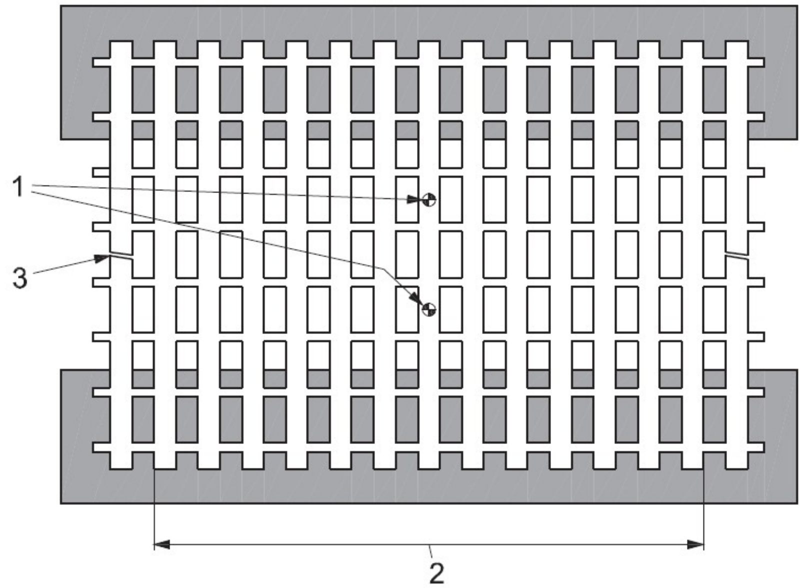



Figure 6.2: Reference points for mounting of extensometer on a typical geogrid with two axes (ISO 2015)

## Calculations

Various results can be obtained from the test, as the tensile strength $T_{max}$, tensile strain at tensile strength, tensile strain at nominal tensile strength and secant stiffness.

### Tensile strength

For woven and nonwoven geotextiles the tensile strength is calculated as:

$$\begin{aligned} T_{max} &= F_{max} \cdot c \\ &= F_{max} \cdot \frac{1}{B} \end{aligned} \tag{6.1}$$

where $F_{max}$ = maximum tensile force [kN] and $B$ = nominal width of the specimen [m].

For geogrids the tensile strength is calculated as:

$$\begin{aligned} T_{max} &= F_{max} \cdot c \\ &= F_{max} \cdot \frac{N_m}{n_s} \end{aligned} \tag{6.2}$$

where $N_m$ = average number of tensile elements within a 1 m width of the product and $n_s$ = number of tensile elements within the test specimen.

**Tensile strain at tensile strength**

The tensile strain is simply read at the maximum tensile strength. It is read to the nearest 0,1 % and given in percent.

**Tensile strain at nominal tensile strength**

At the guaranteed strength given by the manufacturer, also referred to as the nominal tensile strength, the strain is recorded in percent. It is read to the nearest 0,1 %.

**Secant stiffness**

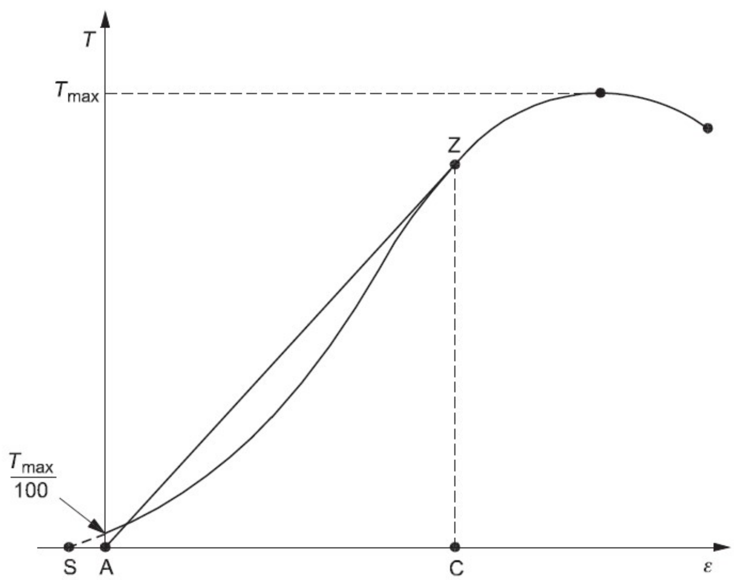



Figure 6.3: Typical load per unit width/strain curve for wide width tensile tests (ISO 2015)

The secant stiffness can be found at a specific strain. It is done as follows:

$$J = \frac{F \cdot c \cdot 100}{\epsilon} \tag{6.3}$$

where $F$ = determined force at the given strain [kN], $\epsilon$ = specific strain [%] and $c$ is given in the previous.

## Results

For each test it is chosen to present all the graphs besides each other. This is done to better understand how each test has developed. Normally the results could have been presented together, showing the mean, maximum and minimum values. Some of the tests have results that are largely influenced by the clamps, and the results are easier discussed with the graphs besides each other.

## Notes

ASTM D4595 (ASTM 2017), the American standard, suggests that six specimens are tested while ISO 10319 suggests five. A greater data base will lead to more accurate results. The best option would be to test as many specimens as possible from the entire batch. Of course this is not possible to do, so at one place a number needs to be set. Whereas the data base will be greater with six specimens it will be less time consuming with five specimens.

The American standard runs at a strain rate of 10% per minute, corresponding to 10 mm per minute on a 100 mm test. The European runs at 20% per minute for geosynthetics with a strain in excess of 5 % and for geosythetics with strain less than or equal to 5 % the specimen shoul break in 30 ± 5 seconds.

As found during testing there is a large variation in results depending on what grips and faces that are used. Research on clamping of geogrids in tensile testing has been carried out by Muller-Rochholz & Recker (2000). The testing problems increase with increasing strength, decreased deformation at rupture and sensitivity to lateral stress. High strength geosynthetics and fabrics made of high modulus and high tenacity fibers are more difficult to test. Such fibers will be polyester, aramid, glass, carbon, and basalt fibers.

## 6.2 Testing at NTNU in Trondheim, Norway

The purpose of the testing at NTNU was to get to know the material better before testing at Statens Vegvesen and KIWA. The testing was done based on ISO 10319 but the standard was not followed well enough to say that the tests are done according to the standard.

With good help from staff in the geotechnics lab, Karl Ivar Volden Kvisvik and Per Asbjørn Østensen, an old machine was refurbished. The machine had not been in use for at least 20 years it was said. The hydraulic system for the load cell was okay. There was a leak in one of the hoses which had to be replaced. The clamp system is a split capstan variant. An overview of the test apparatus is shown in Figure 6.4.

(a) Setup of the machine

(b) Hydraulic system for load cell

Figure 6.4: Test apparatus for wide width tensile test at NTNU

### 6.2.1 Televev 70/70

Before testing the basalt products, a product with known properties was tested. This was done to see whether the machine delivered trustworthy results or not.

The product tested for calibration was a Televev 70/70. It had been delivered from EB Marine together with their basalt product for this purpose. The Televev 70/70 is a well known product that has been used for more than 20 years. According to the producer Geosyntia, Televev is a specially made high-strength fabric. It is produced of polyester yarn woven. The product is delivered with strengths from 70 kN/m up to 1000 kN/m or even 1400 kN/m on order. The producer state that it has little strain even under high load.

### Test setup

When testing the Televev 70/70 some challenges arose.

Cutting of the material was one challenge, although a minor one. The polyester felt soft and difficult to cut with a scissor. To get the exact dimensions with the use of a pen, ruler and scissor required some concentration.

Before the test starts the distance between the clamps or the length of the test specimen should be 100 ± 3 mm. The standard excepts geosynthetics mounted on capstan grips from this. As mentioned the clamps at NTNU were a split capstan variant. To mount the specimen, one of the two parts on the clamp was dismantled. The specimen was then rolled around this part a couple of times. This was done to make the specimen stay in the clamps during the test and to try to avoid slippage. Then it was mounted again. It was found easiest to mount the specimen in the top before it was mounted in the bottom. When mounting in the bottom, the specimen had to be placed so that the clamp hit the bolt that holds the two clamps together. At the same time the fabric should not be stretched during attachment. It should neither be too slack. With the setup at NTNU the installation of the specimens in the apparatus was a challenge.

The top mount and the bottom mount were not completely parallel. This would mean that the tensile force will be distributed unevenly over the fabric. This is undesirable as it means that one part of the fabric is exposed to greater forces than the other, and thus will be more likely to fail faster. It could look as if the rig had fallen to the ground earlier and that the frame had been bent. Attempts were made to rectify this. It helped, but the frame was still somewhat skewed.

Either way the specimens were mounted in the rig and initial tests were carried out with the existing circumstances.

### Results

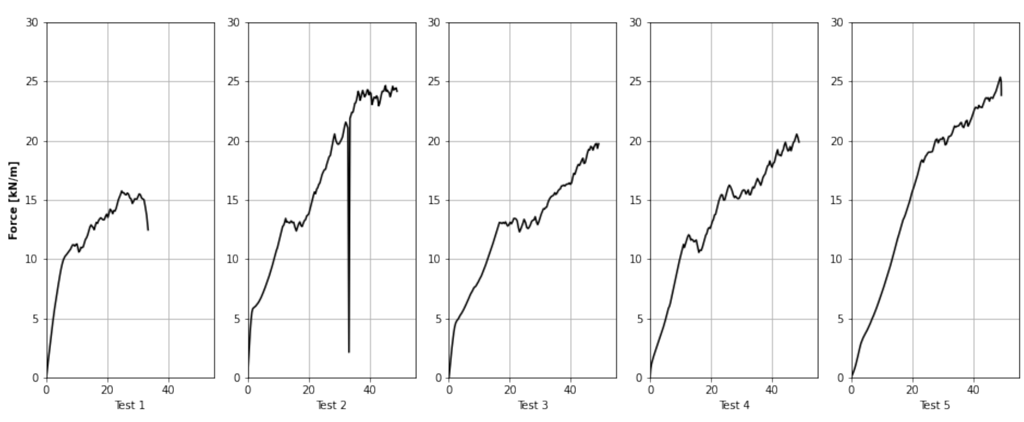



Figure 6.5: Preliminary tests on Televev 70/70

**Evaluation of performance**

As seen in Figure 6.5 most of the graphs have an almost linear behaviour in the beginning. This is especially the case for test 1, 4 and 5. For test 2 and 3, there is a significant bend in the curve at around 5 kN/m.

Common for all of the tests is that the rupture occurred very close to the bottom clamp. According to the standard, measurements should be taken if the test specimen slips in the jaws or if more than one quarter of the specimens break at a point within 5 mm of the edge of the jaw. Both happened during this testing. Ideally the rupture would have occurred more than 5 mm from the edge of the jaw and closer to the middle of the specimen.

The following section is found in the standard in chapter 8.4 (ISO 2015):

> *"It is difficult to determine the precise reason why certain specimens break near the edge of the jaws. If a jaw break is caused by damage to the test specimen by the jaws, the result should be discarded. If, however, it is merely due to randomly distributed weaknesses in the test specimen, it is a legitimate result. In some cases, it may also be caused by a concentration of stress in the area adjacent to the jaws because they prevent the test specimen from contracting in width as the load is applied. In these cases, a break near the edge of the jaws is inevitable and should be accepted as a characteristic of the particular method of test."*

Another concern regarding the tests performed is that the achieved strength is much lower than expected. Televev 70/70 should have a tensile strength of 70 kN/m in both MD and CMD. The maximum force registered is approximately 25 kN/m. This value is 36 % of the expected value. That is a huge difference.

This can be due to various reasons. First, it is not guaranteed that the correct product has been delivered. The wrong product may have been delivered or the product may have been exposed to conditions that have weakened the mechanical properties. No product data was attached to the sample sent, but it is assumed that the product tested is Televev 70/70.

Another reason may be that the equipment is out of date and may be defective. There was a suspicion that the registration of forces could be wrong. By placing a weight of known mass on the piston, the logged force could be read. The read force matched with the applied force.

The elongation of the specimen was recorded using an improvised solution. The extensometer in the form of a deflectometer was not attached to the specimen itself. It was fastened in connection with the lower grips. The elongation that is registered is therefore not the extension of the test piece itself, which should be registered with a distance of 60 mm, but the extension of the distance between the grips. The upper grips are fixed so it is just the extension of the lower grip that is measured. An attempt was made to find a solution to measure the elongation of the test piece itself, but no equipment was available to achieve this. The extension measured can therefore not be used to study the elongation of the specimens and to find the correct strain.

The main reason for the strange results is probably related to the grips. These are of the split capstan type. Severe slippage was observed on all tests. Attempts were made to prevent this by passing the specimens several times around the grips and then tightening the grips vigorously. It was not sufficient. As mentioned, it was complicated to get the test pieces installed in the grips in a good way. Most likely, the grips also had an edge that has been too sharp. The top fasteners and the bottom fasteners were not parallel and the effect of this was probably that the test pieces were pulled over a sharp edge which provoked a fracture. The grips were fastened together using two screws, one at each end. This probably led to the test piece being more squeezed against the outer edges of the grips as the forces were greatest here. The tendency of all the tests was that the fracture occurred just at the edge of the lower grips.

The preliminary tests performed on Televev 70/70 at NTNU showed that the results could not be trusted.

### 6.2.2 EB geotextile

Although the results from the Televev 70/70 tests was rather poor it was decided to run one test on the EB geotextile. The main purpose was to get to know the material better and how it behaves, even though the results could not be trusted. The strength of the product was uncertain while the strain was expected to be somewhere around 3 % at failure.

#### Test setup

In the same way as for the Televev 70/70 the specimen had to be rolled around the grips before the two parts of the grip were assembled. Some attempts were made to achieve this. After the specimen was installed the test was performed.

#### Results

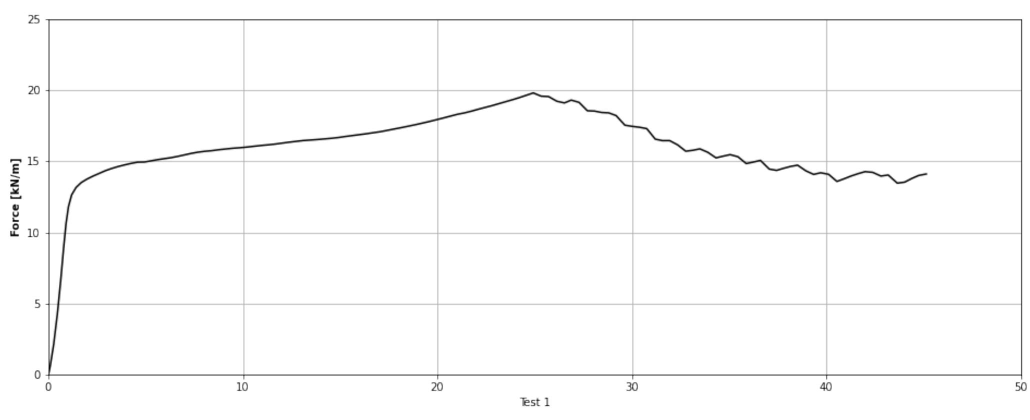



Figure 6.6: Preliminary test on EB geotextile

#### Evaluation of performance

Results are shown in Figure 6.6. The expected strain was as mentioned on around 3 % at rupture. The results from this test does not show anything close to that. Also in this test severe slippage was observed.

Although the results from the performed tests were rather poor they provided some knowledge regarding the testing and on the material. To get some experience before testing in other laboratories was desirable. The results can not be used for anything more than experience. The testing here highlights the importance of proper equipment.

## 6.3 Testing at Statens Vegvesen in Oslo, Norway

Further testing was performed in the laboratory of the Norwegian Public Roads Administration (Statens Vegvesen) in Oslo, Norway. The connection was made through a PhD candidate at NTNU who previously had worked for them. The laboratory regularly tests wovens and non wovens. Proper test equipment was available.

The laboratory has two tensile test machines. One of them is an MTS Alliance RT/100 machine with mechanical grips and clip-on extensometer. The other one is an Instron 3382 machine with hydraulic grips with different faces and video extensometer. Unfortunately the Instron machine was defect and could not be used. It would be favourable to use this machine due to the possibilities to change the faces of the grips and because it has hydraulic grips. In addition the video extensometer would be preferable as the strains are small and high accuracy is needed for the measurements. The tests were therefore performed on the MTS machine.

The mechanical grips on the MTS machine are fastened by two screws that distributes the forces more or less evenly over the entire width through a bar. This is shown in Figure 6.7. The insides of the grips are wavy and have the shape of a wegde with a very small angle. The opening of the grips towards the middle of the test specimen is more open than the part furthest away from the middle. This is done to prevent slippage. In this way the specimen is not squeezed too much at the edges of the jaws which could lead to a fracture in this area. Figure 6.7 also shows the clip-on extensometer which is easily clipped on and off.

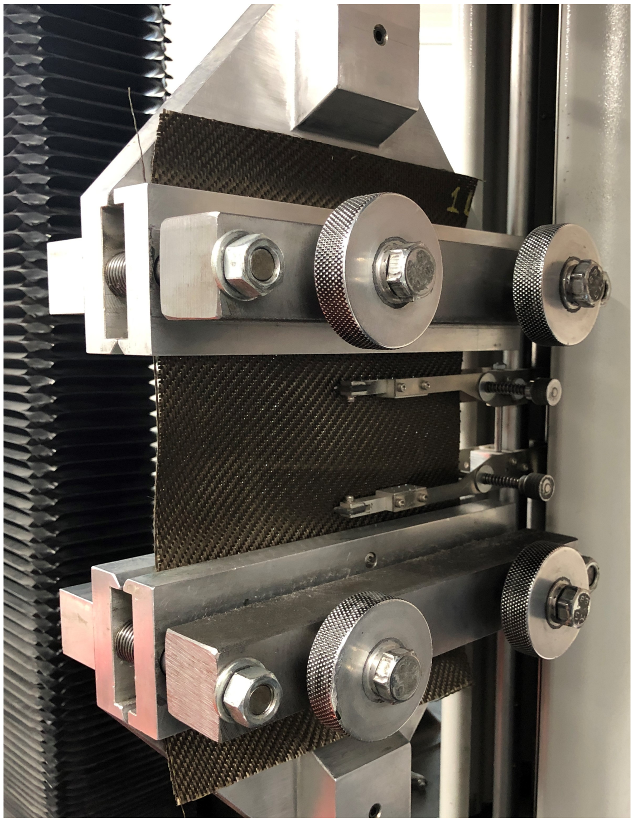


Figure 6.7: Grips and extensometer on MTS machine

All of the tests were performed according to the standard as previously described. In some cases slippage was observed, but it was nowhere near the slippage observed while testing at NTNU.

### 6.3.1 Televev 70/70

The Televev 70/70 was tested first. This was done to see if the results were more accurate than the ones from NTNU.

**Results**

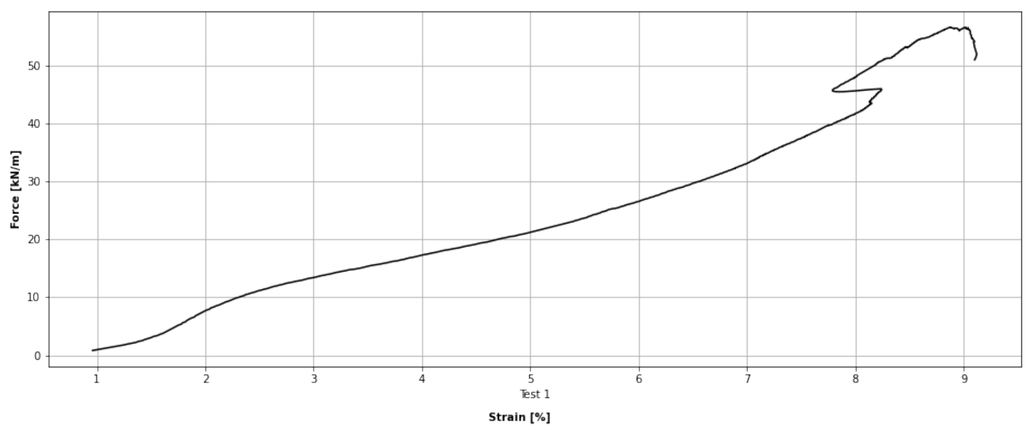



Figure 6.8: Tensile test on Televev 70/70

**Evaluation of performance**

Results from the tensile test on Televev 70/70 are shown in Figure 6.8. The test gave a maximum tensile strength of 56,7 kN/m. This is approximately 80 % of the stated strength. Although this is not as strong as stated it indicates that the results from the MTS machine are more trustworthy. As the nominal tensile strength was not reached, it may also indicate that the grips and the faces are not optimized for testing of this material.

### 6.3.2 EB geotextile

The EB geotextile was prepared for testing and cut as shown in Figure 6.9. Five of the specimens were used for tensile testing. Specimen number six was used in hydraulic testing, which will be presented later. Even though five pieces were cut for testing the results are only shown for four tests. One of the tests got some technical problems and was omitted.

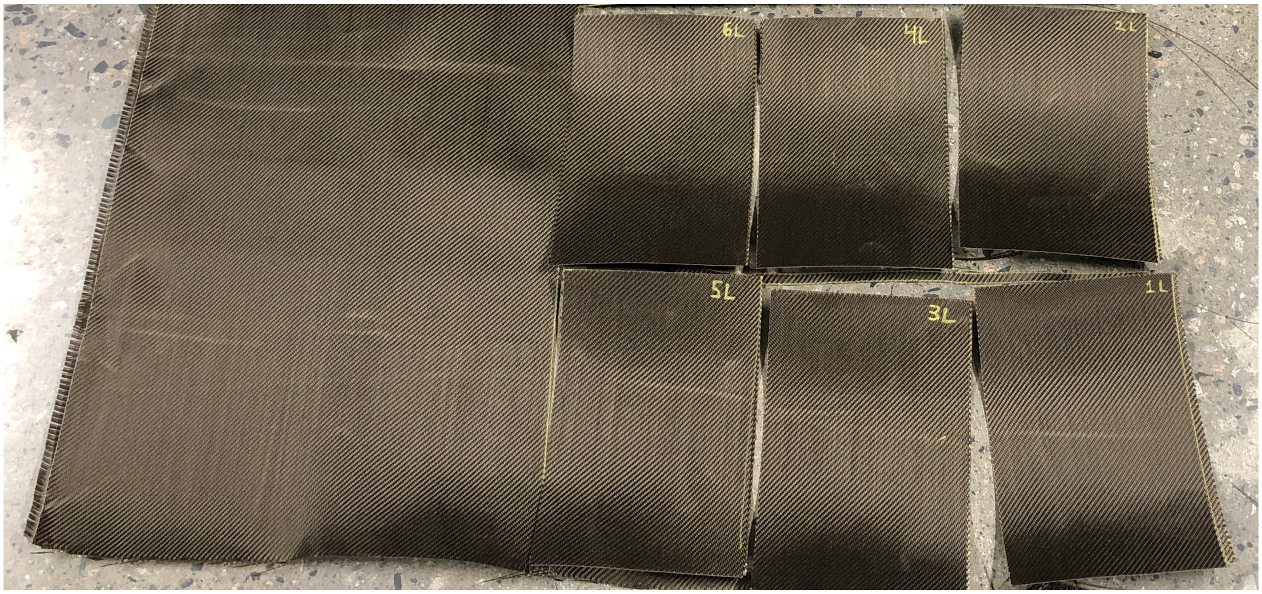



Figure 6.9: Preparation of EB geotextile specimens

Table 6.1: Test data for tensile testing of EB geotextile at Statens Vegvesen

| **Test data** | |
|---|---|
| Material | EB geotextile |
| Test norm | ISO 10319:2015 |
| Date | 22.03.2022 |
| Test direction | MD |
| Condition of specimen | Dry |
| Specimen width | 200 mm |
| Specimen weight | 38,48 g |
| LE | 100 mm |
| Type of testing machine | MTS Alliance RT/100 |
| Load cell | 600 kN |
| Extensometer (path) | Clip-on |

### Results

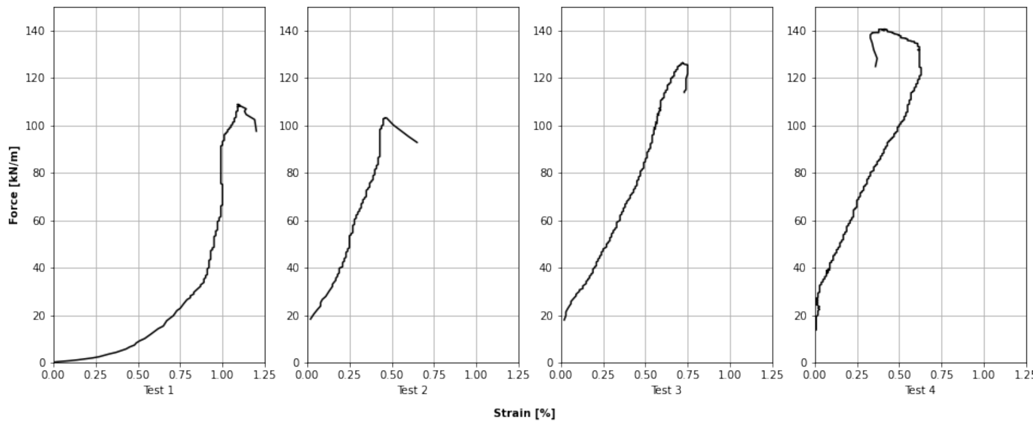



Figure 6.10: Force [kN/m] vs strain [%] for EB geotextile in MD

Table 6.2: Statistics from wide width tensile test on EB geotextile in MD

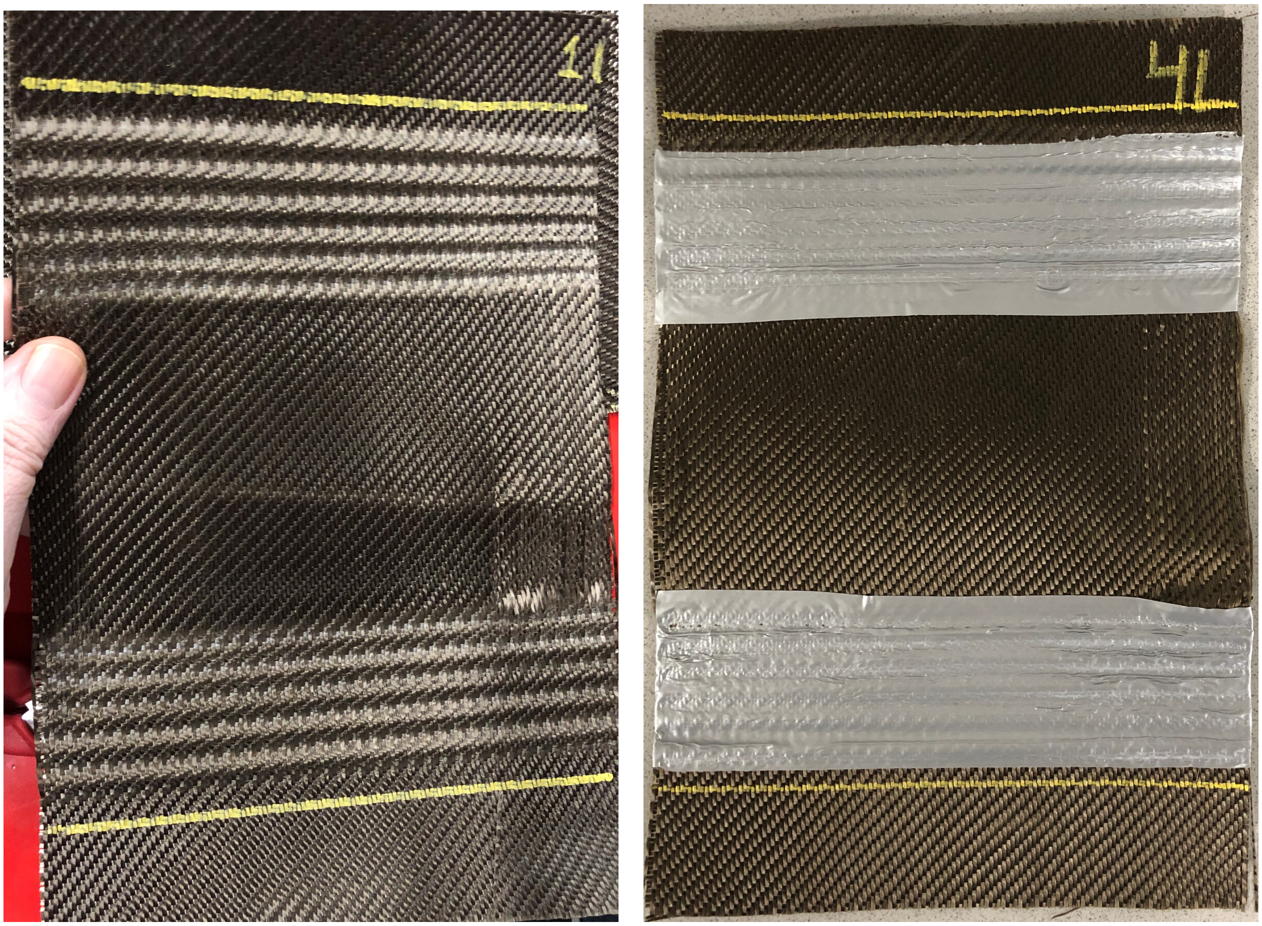
| n=4 | Fm [N] | Fm [kN/m] | Am [%] |
|---|---|---|---|
| $\bar{x}$ | 23,94 | 119,70 | 0,7 |
| s | 2,95 | 17,03 | 0,3 |

### Evaluation of performance

Results from tensile testing of EB geotextile are given in Figure 6.10 and Table 6.2. Some slippage was observed for test 1 and 2. Therefore test 3 and 4 were taped with duct tape in the clamping area to try to avoid slippage. One round of duct tape was applied. The graphs for test 3 and 4 do not differ very much from the ones of test 1 and 2. This may indicate that the effect of the taping was minimal for the product.

Another reason for taping was to try to force the failure away from the clamps. In test 1 and 2 the failure occured close to the clamps. Unfortunately the failure still happened in the same area on the taped specimens, so that the tape proved to have minimal effect for this problem. Normally Statens Vegvesen test non-wovens in this machine with these clamps. They are often thicker than the basalt products. The grips are normally not an issue for testing of these kinds of products.

The reached strain at failure was under 1 % for all tests except from test 1. If test 1 had been preloaded as the other ones it is believed that this one also would reach a strain under 1 %. This is lower than expected. It is believed that this has to do with the curvature of the waves on the grips. As the material is stiff and brittle it is prone to fail if it is bent too much. This may have happened in the tests. When the specimens are put under tension they will want to straighten out but will be hindered by the wave formations in the grips. This will lead to concentrated forces and may provoke a failure. The marks from the grips as well as the failure can be seen in Figure 6.11. In the figure it can also be seen that the failure happened in the lower right area. It is also believed that the strain measurements may not be sufficiently accurate.



(a) Pattern from the grips on the test specimen

(b) Specimen protected with duct tape

Figure 6.11: Failure of EB geotextile specimens in wide width tensile tests at Statens Vegvesen

The graph for test 4 in Figure 6.10 is behaving normal until it reaches a force around 120 kN/m. From there it moves upwards and to the left, meaning that the force continues to increase while the strain decreases. The grips for the extensometer are mounted in the middle of the specimen width. When a rupture occurs near the border of the specimen, which was the case for this test, the specimen contracted in the middle. This is the reason for the shape of the curve.

The graph for test 1 starts at zero force whereas the other tests start at approximately 20 kN/m. This is due to the pretension. Test 1 has been installed in the machine so that there has been some slack in the fabric. It has not been fully extended. Due to this the start of the graph is really not of interest. The other tests start at around 20 kN/m force. When the specimens are placed in the machine and the screws on the grips are fastened the fabric is put under tension. Ideally the tests should all be preloaded to 1 % of their ultimate tensile strength.

As the tests start the logging at approximately 20 kN/m a lot of the development of the strain is lost. This is because the prestress has been higher than it should have been. It should have been 1 % of the tensile strength. As has been seen from the previous results presented the basalt products tend to have a linear curve. If a regression is made based on the curves presented in Figure 6.10 the strain at zero force would be -0,25 % for test 2 so that the strain at failure would be $0,25+0,4=0,65\%$. For test 3 the strain at zero force would be -0,2 % causing the strain at failure to be $0,2+0,7=0,9\%$. For test 4 the strain at zero force would be -0,25 % and the maximum strain would be 0,75 %, so that the strain at failure would be $0,25+0,75=1,0\%$.

Slippage of the extensometer on the fabric was observed. The fabric has a relatively slippery surface, and paired with the metal clip-on extensometer the strain measurements may contain errors.

### 6.3.3 RT geogrid

As the results from the testing of the EB geotextile showed that the clamps were not suited for this material it was decided to only test a few specimens.

Table 6.3: Test data for tensile testing of RT geogrid at Statens Vegvesen

| **Test data** | |
|---|---|
| Material | RT geogrid |
| Test norm | ISO 10319:2015 |
| Date | 22.03.2022 |
| Test direction | MD |
| Condition of specimen | Dry |
| Specimen width | 200 mm |
| Threads / specimen | 6 |
| LE | 100 mm |
| Type of testing machine | MTS Alliance RT/100 |
| Load cell | 600 kN |
| Extensometer (path) | Clip-on |

**Results**

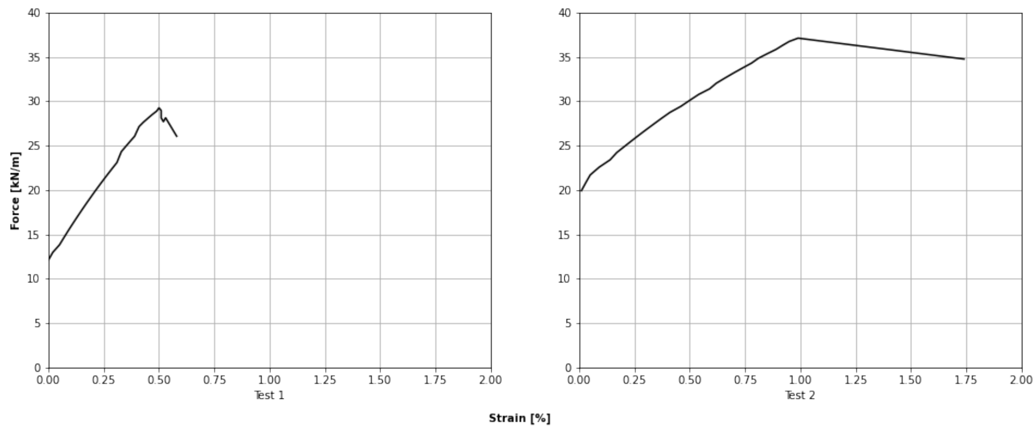



Figure 6.12: Force [kN/m] vs strain [%] for RT geogrid in MD

Table 6.4: Statistics from wide width tensile test on RT geogrid in MD

| n=2 | Fm [kN] | Fm [kN/m] | Am [%] |
|---|---|---|---|
| $\bar{x}$ | 5,97 | 29,87 | 0,7 |
| s | 1,39 | 6,95 | 0,3 |

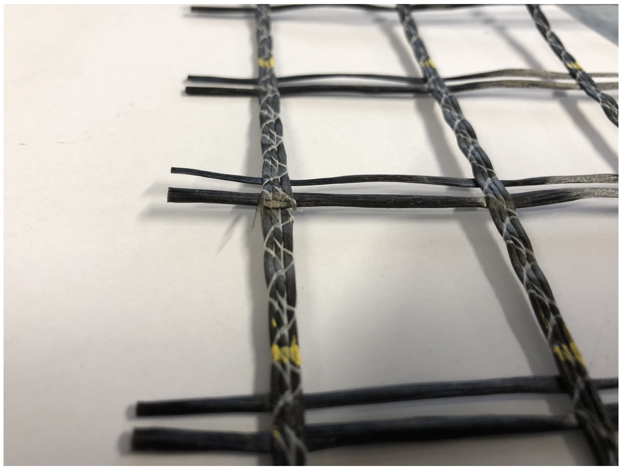
**Evaluation of performance**

Results from testing are shown in Figure 6.12 and Table 6.4. When testing the RT geogrid the main challenge was also related to the clamps. When the specimens were installed they were fastened in the upper clamps first. Thereafter they were placed in the lower clamps and tightened. When tightening the last clamps a stress was applied to the specimen. This can be seen in Figure 6.12. Test 1 starts at 12,5 kN/m while test 2 starts at 20 kN/m. These values should be 1 % of the tensile strength. The specimens were tried installed with zero pretension and then stretched to initial position, but this led to an uneven fastening.

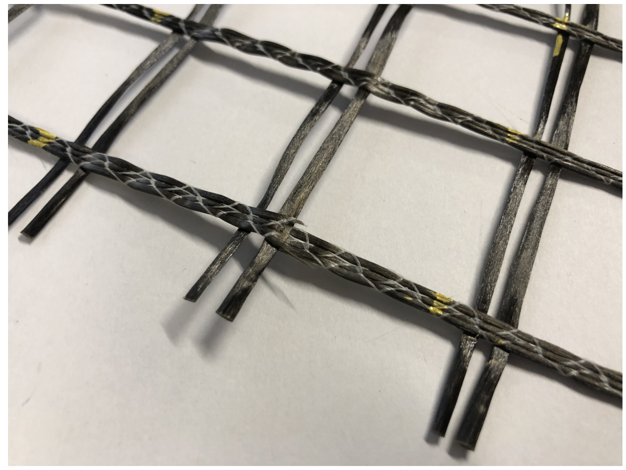
As the tests start the logging at 12,5 and 20 kN/m a lot of the development of the strain is lost. If a regression is made based on the curves presented in Figure 6.12 the strain at zero force would be -0,37 % for test 1 so that the strain at failure would be $0,37+0,5=0,87\%$. For test 2 the strain at zero force would be -1,17 % causing the strain at failure to be $.17+1,0=2,17\%$. The value then obtained from test 2 will be closer to the values of the previous tests that are presented on other basalt products.

For these tests the failure occurred inside the clamping area. The force used to tighten the clamps has probably been too high. This force is not measured and displayed, so the tightening is done based on experience. This problem causes a premature failure of the specimen. The true strength parameters are not found. Pictures of the failure are shown in Figure 6.13.

The challenge related to the extensometer was the same for the RT geogrid. The strain measurements do not seem to have captured the strains correctly.



(a) Failure in the clamping area on RT geogrid



(b) Failure of test specimen

Figure 6.13: Failure of RT geogrids in wide width tensile tests at Statens Vegvesen

## 6.4 Testing at KIWA in Greven, Germany

KIWA, or former TBU, is a laboratory specialized in testing of building materials and especially geosynthetics. Following are the results from wide width tensile testing on the EB geotextile and RT geogrid done at KIWA's lab. Tests are performed on the reference specimens and the damaged specimens that have been damage tested according to ISO 10722 and discussed in Chapter 5.

### 6.4.1 EB geotextile

Table 6.5: Test data for tensile testing of EB geotextile at KIWA

| **Test data** | |
|---|---|
| Material | EB geotextile |
| Test norm | ISO 10319:2015-09 |
| Date | 27.04.2022 |
| Test direction | MD |
| Condition of specimen | Dry |
| Specimen width | 200,0 mm |
| LE | 100 mm |
| Pre-load | 490 N |
| Type of testing machine | Zwick Z600 |
| Load cell | 600 kN |
| Extensometer (path) | Video |
| Specimen grips | VAS V.600.HY.HY.1 |
| | (200 mm x 480 mm Vulkollan) |
| Climate | 21 ° C / 34 % relative humidity |
| F0 = Force at | 0,5 % |
| F1 = Force at | 1 % |
| F3 = Force at | 2 % |

**Results**

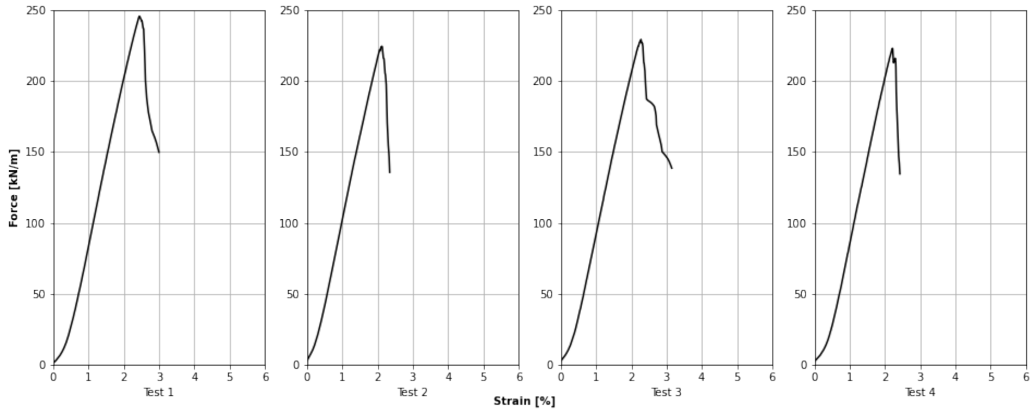



Figure 6.14: Force [kN/m] vs strain [%] for reference EB basalt geotextile in MD

Table 6.6: Statistics from wide width tensile test on reference EB basalt geotextile in MD

| n=5 | Fm [N] | Fm [kN/m] | Am [%] | F0 [kN/m] | F1 [kN/m] | F3 [kN/m] | t-F max [s] |
|---|---|---|---|---|---|---|---|
| $\bar{x}$ | 46 115 | 230,57 | 2,26 | 32,46 | 91,02 | 206,73 | 29,58 |
| s | 2080 | 10,40 | 0,13 | 6,83 | 8,57 | 6,64 | 4,40 |
| V | 4,51 | 4,51 | 5,95 | 21,05 | 9,42 | 3,21 | 14,88 |

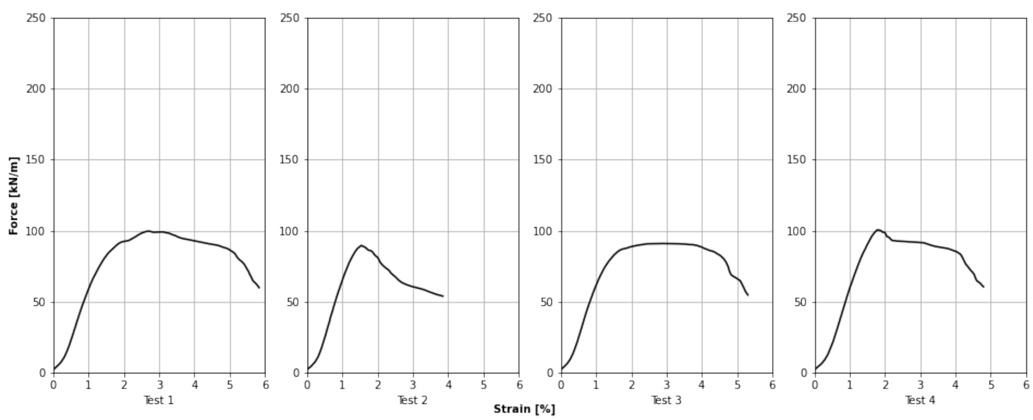



Figure 6.15: Force [kN/m] vs strain [%] for damaged EB basalt geotextile in MD

Table 6.7: Statistics from wide width tensile test on damaged EB basalt geotextile in MD

| n=5 | Fm [N] | Fm [kN/m] | Am [%] | F0 [kN/m] | F1 [kN/m] | F3 [kN/m] | t-F max [s] |
|---|---|---|---|---|---|---|---|
| $\bar{x}$ | 19 035 | 95,18 | 2,26 | 22,99 | 61,32 | 90,55 | 17,89 |
| s | 1140 | 5,70 | 0,70 | 2,03 | 2,81 | 2,57 | 0,34 |
| V | 5,99 | 5,99 | 31,01 | 8,83 | 4,58 | 2,84 | 1,93 |

**Evaluation of performance**

When mounting the specimens in the machine the pressure on the clamps needs to be chosen. The optimal hydraulic pressure will depend on the cumulative effective area of the clamping cylinders. It should be sufficient so that no slippage occurs. At the same time it should should not be so high that the product is damaged. A pressure of 100, 200, and 300 bars were used. For the EB geotextile a pressure of 200 bars gave the best results. The differences were not very big.

In the previous tests mechanical clamps with metallic faces have been used. In this test the faces were made of Vulkollan. Vulkollan is an elastomer with characteristics as high tensile strength and tear resistance, as well as low compression and abrasion loss. For basalt products and other stiff and brittle products it is found to be a preferred face material.

The graphs from the testing of the reference specimens and the damaged specimens are scaled equally. The maximum on the y-scale is 250 kN/m and the maximum on the x-scale is 6 % strain for all graphs. This is done to clearly higlight the differences between the reference specimens and damaged specimens.

The mean tensile strength from the reference specimens is 230,57 kN/m while the mean tensile strength is 95,18 kN/m for the damaged specimens. In other words the product lost almost 60 % of its' strength in the damage testing. That is a serious reduction in strength.

At the same time, both the reference specimens and the damaged specimens reached a strain of 2,26 % at failure. No changes have taken place here.

The tests show that this product is highly vulnerable to damage caused by granular materials. Granular materials with sharp edges have the ability to cut through and puncture the stiff and brittle basalt fibers. When the fabric is punctured the effective width of the specimen will decrease. This again will lead to higher stresses in the fabric and less force is required to make it fail. For installations including sharp granular materials this is a big concern for this product.

### 6.4.2 RT geogrid

Table 6.8: Test data for tensile testing of RT geogrid at KIWA

| Test data | |
|---|---|
| Material | RT geogrid |
| Test norm | ISO 10319:2015-09 |
| Date | 27.04.2022 |
| Test direction | MD |
| Condition of specimen | Dry |
| Specimen width | 236,3 mm |
| Test strands | 7 |
| Strands / m | 29,6 |
| LE | 100 mm |
| Pre-load | 490 N |
| Type of testing machine | Zwick Z600 |
| Load cell | 600 kN |
| Extensometer (path) | Video |
| Specimen grips | VAS V.600.HY.HY.1 |
| | (200 mm x 480 mm) |
| Climate | 21 ° C / 34 % relative humidity |
| F0 = Force at | 0,5 % |
| F1 = Force at | 1 % |
| F3 = Force at | 2 % |

**Results**

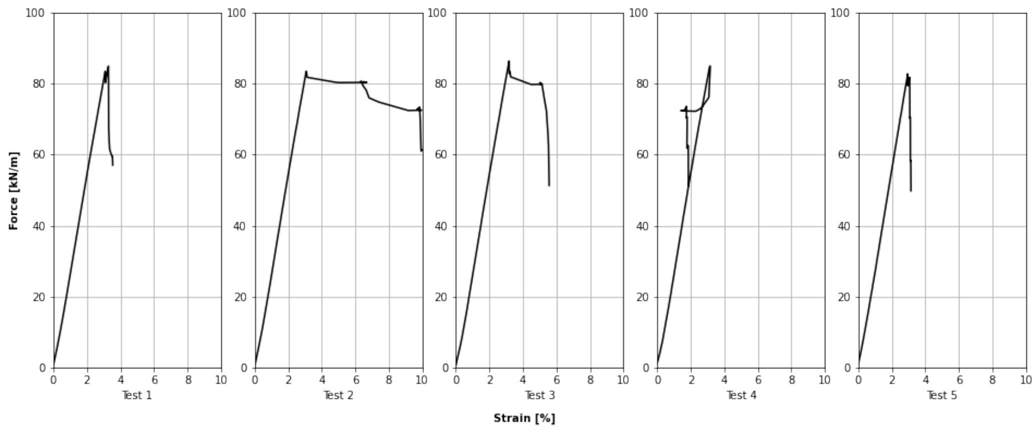



Figure 6.16: Force [kN/m] vs strain [%] for undamaged RT basalt geogrid in MD

Table 6.9: Statistics from wide width tensile test on reference RT basalt geogrid in MD

| n=5 | Fm [N] | Fm [kN/m] | Am [%] | F0 [kN/m] | F1 [kN/m] | F3 [kN/m] | t-F max [s] |
|---|---|---|---|---|---|---|---|
| $\bar{x}$ | 19 960 | 84,47 | 3,13 | 12,31 | 26,10 | 54,65 | 30,60 |
| s | 332 | 1,40 | 0,13 | 0,56 | 0,47 | 0,70 | 1,11 |
| V | 1,66 | 1,66 | 4,01 | 4,59 | 1,81 | 1,28 | 3,63 |

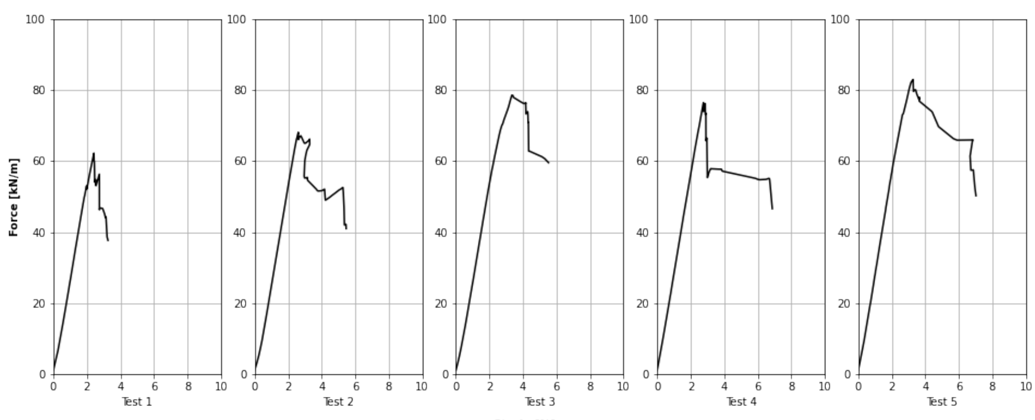



Figure 6.17: Force [kN/m] vs strain [%] for damaged RT basalt geogrid in MD

Table 6.10: Statistics from wide width tensile test on damaged RT basalt geogrid in MD

| n=5 | Fm [N] | Fm [kN/m] | Am [%] | F0 [kN/m] | F1 [kN/m] | F3 [kN/m] | t-F max [s] |
|---|---|---|---|---|---|---|---|
| $\bar{x}$ | 17 405 | 73,66 | 2,88 | 12,63 | 26,55 | 54,41 | 26,68 |
| s | 1975 | 8,36 | 0,41 | 1,28 | 1,43 | 2,03 | 2,77 |
| V | 11,35 | 11,35 | 14,35 | 10,17 | 5,40 | 3,73 | 10,40 |

**Evaluation of performance**

All of the graphs in Figures 6.16 and 6.17 show a linear behaviour as the previous tests also have done. The failure is brittle.

The reference specimens reached a mean tensile strength of 84,47 kN/m. The damaged specimens reached a mean tensile strength of 73,66 kN/m. The difference is way less than for the EB geotextile. Approximately 13 % of the strength is lost due to the damage.

The damaged specimens achieved a lower strain than the reference ones. The damaged specimens reached a strain of 2,88 % while the reference specimens reached a strain of 3,13 %. Almost 8 % strain is lost.

The RT geogrid showed results that indicated that the product is less affected by damage from granular material compared to the EB geotextile. This may be because the coating protects the fibers from being cut.

# Chapter 7

# Permeability test

The laboratory at Statens Vegvesen had a test machine available for testing according to ISO 11058 - Determination of water permeability characteristics normal to the plane, without load. The machine was of the type Ge-Te-Flow produced by Lenzing instruments. It was decided to test the properties of the EB geotextile.

The fabrics from basalt fibers may come in numerous types with variable geometries and pore openings. The results from this test will not be representative for geotextiles made from basalt in general. It will only provide the hydraulic properties of the EB geotextile.

Only the EB geotextile is tested. It would not make sense to test the RT geogrid.

## 7.1 The standard

The standard describes test methods for determination of water permeability characteristics for geotextiles and geotextile-related products. The tests can be done in two ways. Either with constant head or with falling head. The falling head procedure is followed in this test and will be mentioned.

### Principle

For the falling head procedure, a unidirectional flow of water is applied normal to the plane of the fabric under a falling head. The flow rate is measured continuously and the permeability is found.

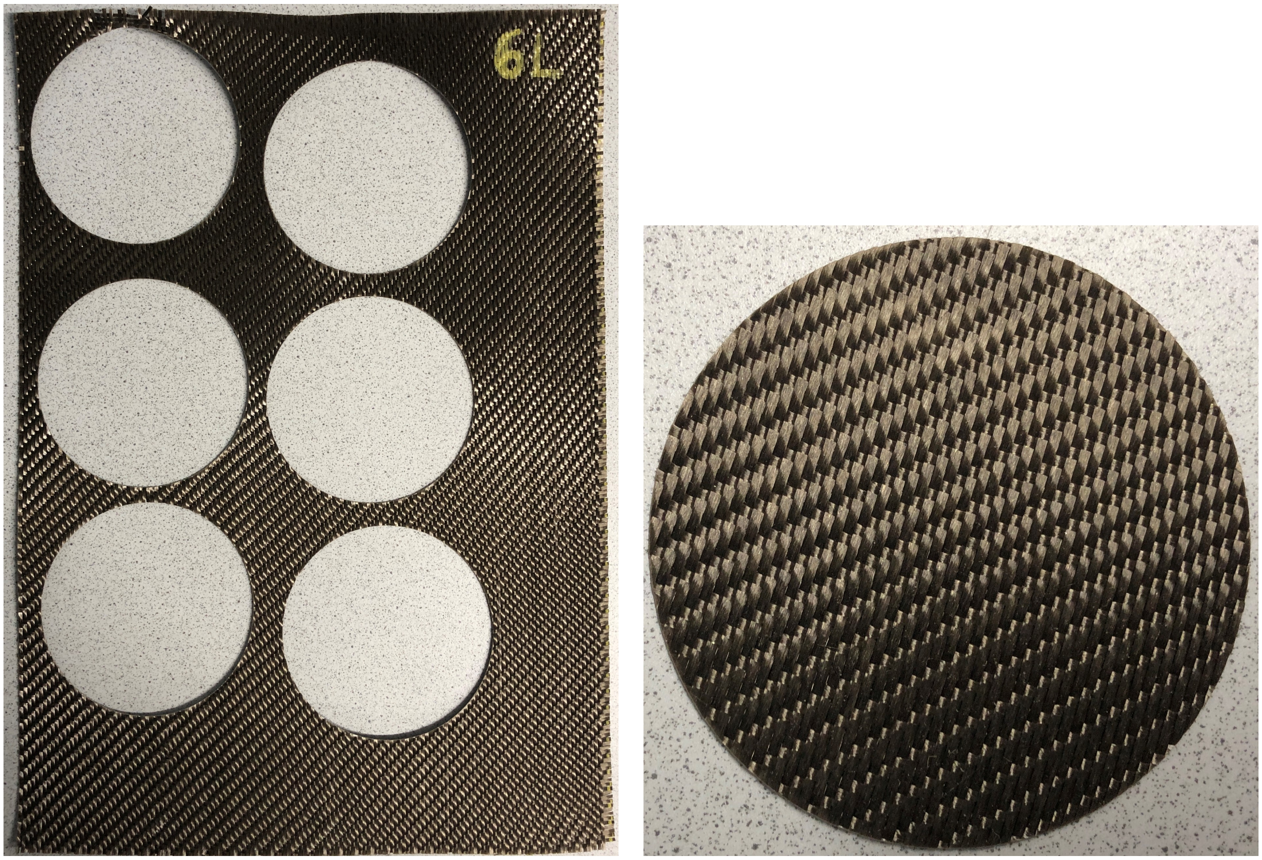
### Apparatus

Several requirements are needed to fulfill the standard. This regards the machine as well as the water supply and the measuring devices. The Ge-Te-Flow fulfills these requirements. A picture of the apparatus is shown in Figure 7.1


Figure 7.1: Ge-Te-Flow test apparatus

## Procedure

The specimens are prepared according to the standard. They are cut to fit the diameter of the apparatus. The specimens are shown in Figure 7.2. They should be put in water containing 0,1 % volume non-ionic surfactant for at least 12 hours. The specimen is then placed in the apparatus, making sure that the system is sealed.




(a) All test specimens

(b) One test specimen

Figure 7.2: Test specimens for permeability testing

A water column is built up automatically in the machine. When the water column reaches its' preset height the test starts. The flow rate passing through the sample is measured and registered continuously. This is done with the use of highly sensitive pressure sensors. When the head loss and the velocity reaches zero the test is stopped. The procedure should be repeated for five test specimens.

## 7.2 Testing at Statens Vegvesen in Oslo, Norway

### 7.2.1 EB geotextile

**Results**

Table 7.1: Test data for permeability test on EB geotextile

| VIH50 | |
|---|---|
| Minimum | 21.12 mm/s |
| Maximum | 26.5 mm/s |
| Average | 24.61 mm/s |
| Standard deviation | 2.21 mm/s |
| Coefficient of variation | 8.99 |

| kv (coefficent of permittivity at 20 °C) | |
|---|---|
| Minimum | 00.00017 m/s |
| Maximum | 00.00019 m/s |
| Average | 00.00018 m/s |
| Standard deviation | 00.00001 m/s |
| Coefficient of variation | 04.81792 |

| Time t required one liter (1L) | |
|---|---|
| Minimum | 10.45 s |
| Maximum | 13.12 s |
| Average | 11.34 s |
| Standard deviation | 1.1 s |
| Coefficient of variation | 9.69 |

| Date of measurement | # | Sample Name | Producer | Temp. °C | VIH50 (v20) | VIHUser | kv | Time sec/l | Sample thickness |
|---|---|---|---|---|---|---|---|---|---|
| 23.03.2022, 10:23 | 1 | 1_Wednesday, March 23, 2022 | EB Marine | 19.7°C | 21.119 mm/s | 31.371 mm/s | 0.000169 m/s | 13.12 s | 0.36 mm |
| 23.03.2022, 10:33 | 2 | 2_Wednesday, March 23, 2022 | EB Marine | 19.8°C | 23.733 mm/s | 35.79 mm/s | 0.0001899 m/s | 11.67 s | 0.36 mm |
| 23.03.2022, 10:40 | 3 | 3_Wednesday, March 23, 2022 | EB Marine | 19.8°C | 25.909 mm/s | 38.1 mm/s | 0.0001865 m/s | 10.69 s | 0.36 mm |
| 23.03.2022, 10:48 | 4 | 4_Wednesday, March 23, 2022 | EB Marine | 19.9°C | 26.502 mm/s | 39.809 mm/s | 0.0001908 m/s | 10.45 s | 0.36 mm |
| 23.03.2022, 11:01 | 5 | 5_Wednesday, March 23, 2022 | EB Marine | 20°C | 25.768 mm/s | 38.674 mm/s | 0.0001855 m/s | 10.75 s | 0.36 mm |

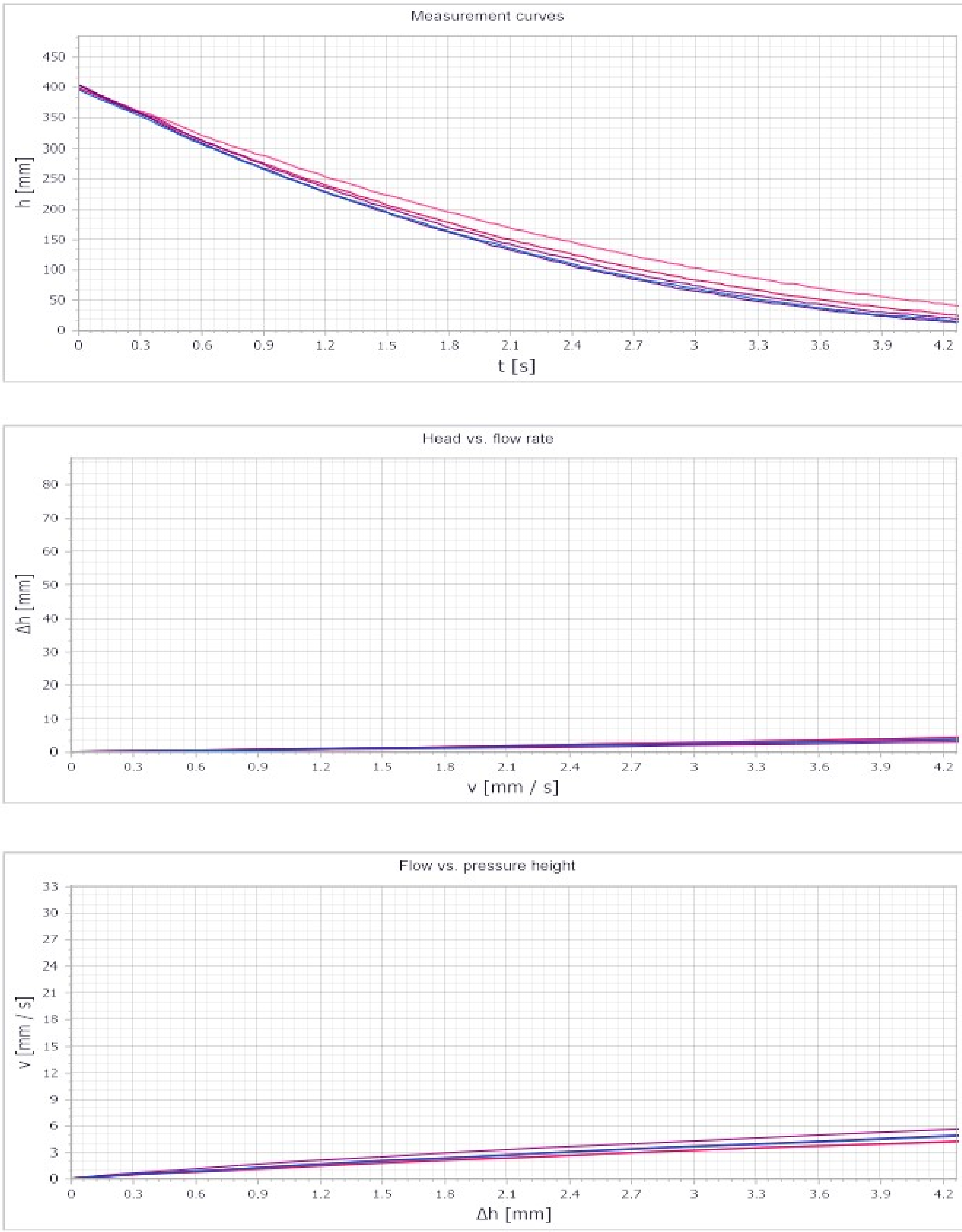



Figure 7.3: Results from permeability tests on EB geotextile

**Evaluation of performance**

As can be seen from the graphs in Figure 7.3 and Table 7.1 the test results from the five different specimens are quite uniform. There are no big deviations from one test specimen to the other. The mean velocity index VIH50 was reported to be 24,61 mm/s. This value is a measure of the flow velocity. The value equals the discharge $q$ expressed in litres per square meter second.

The achieved value may be used in the design. It may be compared to similar products to choose the best option for the specific task. It may also be used to change the geometry of the fabric to get the desired permeability properties.

# Chapter 8

# Discussion

## 8.1 Wide width tensile tests

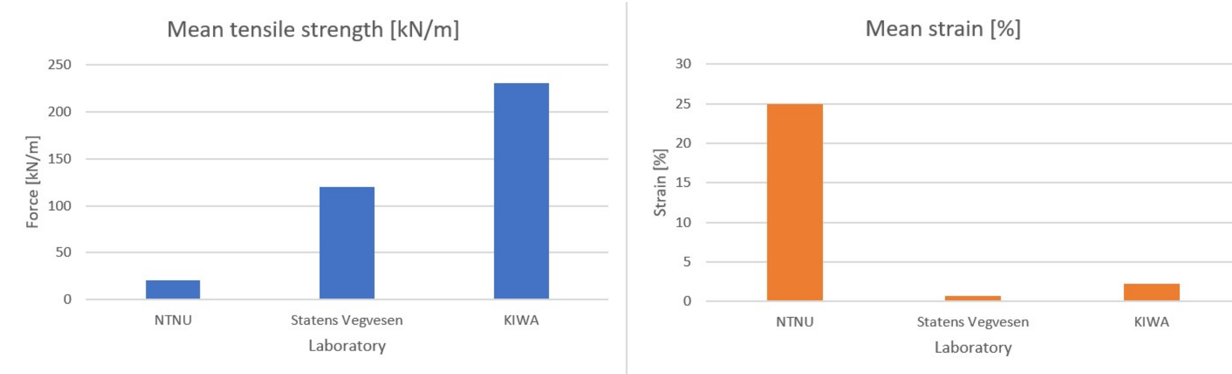
One of the clearest findings during testing is the importance of the equipment that is used. The tests that are carried out for this thesis are carried out on three very different machines.

The machine used at NTNU was old and inaccurate. The strain velocity could not be adjusted. The specimens were hard to install in the split capstan grips, leading to uneven distribution of forces and severe slippage. The machine is not accurate enough to test geosynthetics according to ISO 10319.

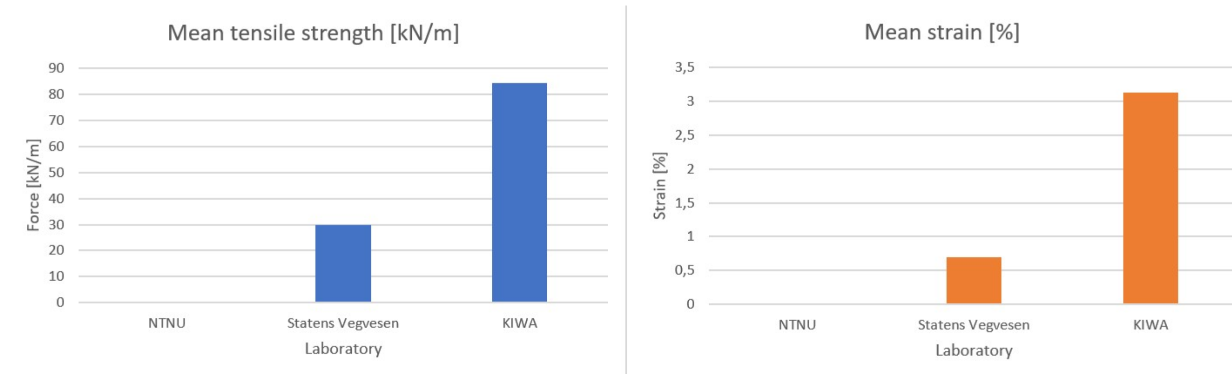
At Statens Vegvesen the equipment is more up to date. It is regularly used to test geosynthetics and especially nonwovens. Better results were obtained here, but problems related to strain measurements, failure in the clamping area and slippage still took place. As mentioned Statens Vegvesen have two machines for tensile testing. One of them was out of order. Unfortunately this was the one that would probably obtain best results for the basalt products.

Luckily such a machine was available at KIWA. The tests with best results, meaning highest reached tensile strengths, were carried out here. These results are trustworthy.

The differences between the laboratories were big. The achieved tensile strengths and strains from each laboratory are compared and summed up in Figure 8.1 and Table 8.1.




(a) Comparison of laboratory results on EB geotextile




(b) Comparison of laboratory results on RT geogrid

Figure 8.1: Comparison of laboratory results from NTNU, Statens Vegvesen and KIWA

Table 8.1: Results from tensile testing of EB geotextile and RT geogrid in different laboratories

| **Laboratory** | **EB geotextile** | | **RT geogrid** | |
|---|---|---|---|---|
| | **Mean tensile strength [kN/m]** | **Mean strain [%]** | **Mean tensile strength [kN/m]** | **Mean strain [%]** |
| NTNU | 20,7 | 25 (slippage) | - | - |
| Statens Vegvesen | 119,70 | 0,7 | 29,87 | 0,7 |
| KIWA | 230,57 | 2,26 | 84,47 | 3,13 |

### 8.1.1 Clamps and grips

The importance of the clamps has really been seen throughout testing. For conventional nonwovens, metallic clamps with mechanical fastening will do the job in a good way in most cases. For more brittle materials this is not the case. It might be that more modern capstan grips than the ones used for testing at NTNU would have worked fairly well. It is still believed that it would be difficult to mount the specimens in a good way.

Muller-Rochholz & Recker (2000) did a study on different clamps and faces for testing according to ISO 10319 and ASTM D4595. In the study an identical product, a PET geogrid with nominal force of 200 kN/m was tested. Depending on the clamps the achieved strengths varied between 194,8 and 224,7 kN/m. The study says that the problems related to testing increase with increasing strength, decreasing deformation at rupture and sensitivity to lateral stresses. The basalt products have a relatively high strength and low strains, so they certainly fall into the description.

As far as the author is concerned there are no guidelines for what grips and face materials that are best for the different product types and materials. The standard says that they should be sufficiently wide to hold the entire width of the specimen and that they should be equipped with appropriate means to limit slippage or damage. It is stated that it is important to choose jaw faces that limit slippage of the specimen, especially for stronger products. What this means is not further specified. Such information would be of great value for everyone involved in the geosynthetic industry. This would lead to better test results, which would be an advantage for both the manufacturer, the designer and the end user.

It is found that the material Vulkollan is one of the best suited ones for testing of basalt. It is an advancement of polyurethane (PU). The material did not damage the material in the same way that the metal ones did. In combination with hydraulic clamps no slippage was detected. This will most likely also be the case for other materials with similar properties as glass, aramid, carbon and the ones alike.

### 8.1.2 Strain measurements

How to measure the strain is of great importance when dealing with low strain products. As the values at failure will be low it is crucial to have high accuracy measurements for the small strains. This is taken care of in a good way in the standard. The standard specifies that the equipment should be able to measure the distance between two reference points on the specimen without any damage or slippage, and that the measurements should represent the true movement of the reference points. The movement should be measured to an accuracy of ± 2 %, which is quite accurate. The standard also says that the extensometer should be mechanical, optical, infrared or other types, all with electrical output.

During testing at Statens Vegvesen a mechanical extensometer was used. The surface of the EB geotextile was somewhat slippery. This made it harder for the extensometer to follow the movements of the specified points as it would slide some. For the RT geogrid this problem became worse. The coating made the surface even more slippery. A non-mechanical extensometer would have been better.

A video extensometer was used at KIWA. To be able to track the movements of the specified points, two small pieces of tape were put on the fabric. The tape was white in contrast to the grey fabric. Before running the test the extensometer was calibrated. With this technique the strains were tracked with high accuracy.

### 8.1.3 Varying results depending on laboratory

The fact that the results may vary a lot from laboratory to laboratory is a big challenge. This challenge already exists and is known. In the study already mentioned by Muller-Rochholz & Recker (2000) another product, a polyester geogrid with nominal force of 40 kN/m was tested in different laboratories. The results obtained varied between 32,5 and 41,6 kN/m. The highest value was found by the producer himself.

To deal with this system a system called Round Robin has been introduced by NorGeoSpec (NorGeoSpec 2012). Products certified and specified according to NorGeoSpec 2012 is used in these rounds. In laboratory A testing to find the mass per unit area (ISO 9864), wide width tensile test (ISO 10319), dynamic perforation resistance (ISO 13433), Permeability normal to the plane without load (ISO 11058), and characteristic opening size (ISO 12956) is performed. These values are used for certification and specification. Samples are then sent to other laboratories in the system to perform a selection of tests. No instructions are given on the test methods other than those in the respective standards. The results from all the labs can then be evaluated.

According to Diederich et al. (2012) there are three important reasons for why the results varies as much as they do. First of all the standards allow a high degree of freedom. There is room for interpretation in almost all. This is an obvious source for varying results. Round Robin tests should be used for discussion in technical committees to further improve the standards. The second reason is due to deviations from the test methods that are described. Some laboratories differ from the standard and do not perform the tests as described. It is clear that such behaviour is inadmissible. These laboratories should be excluded if they are not willing to change their operating procedures. The third and last reason that is mentioned is caused by variations in production. To avoid great differences caused by this, special care should be taken during sample selection. Samples should be cut in a chosen pattern and weaknesses from production should be avoided and reported.

## 8.2 Mechanical and physical properties

To facilitate the discussion around the mechanical properties found for the tested basalt products the results are summed up in Figure 8.2 and Table 8.2. For the EB geotextile and RT geogrid the values obtained from testing at KIWA are used. The highest value obtained from testing of the Fortrac is used.

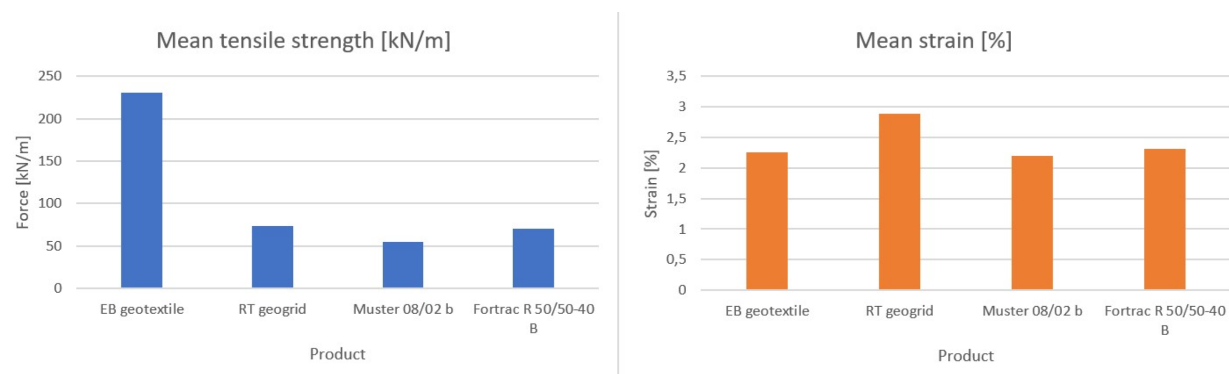



Figure 8.2: Comparison of results from tensile testing

Table 8.2: Summary of test results from tensile tests on basalt products

| Product | Mean tensile strength [kN/m] | Mean strain [%] |
|---|---|---|
| EB geotextile | 230,57 | 2,26 |
| RT geogrid | 73,66 | 2,88 |
| Muster 08/02 b | 54,52 | 2,20 |
| Fortrac R 50/50-40 B | 70,50 | 2,31 |

### 8.2.1 Tensile strength

The geotextile has the highest tensile strength with 230,57 kN/m. This strength is competitive against geotextiles made from polyester. For instance, biaxial wowen Televev fabrics are delivered with strengths between 70 and 200 kN/m. A special product for marine applications is also available in the same range. The uniaxial woven ones can be delivered with up to 1400 kN/m, and other producers have products with even higher strengths produced on demand.

Huesker usually produce their Fortrac series from either Polyethylene terephthalate (PET), or from Polyvinyl alcohol (PVA) in MD and Polypropylene (PP) in CMD. The products produced from PET have a tensile strength from 35 to 800 kN/m, while the PVA and PP has a tensile strength from 35 to 400 kN/m. It should be noted that these values are for stock items. Special products can be produced on demand, with over 2000 kN/m strength. The basalt geogrids with tensile strengths between 55 and 74 kN/m are in the lower spectrum of this range.

### 8.2.2 Strain

It is stated that the PET products have a strain lower than 10 % in both MD and CMD whereas the PVA and PP products have a strain lower than 6 % in MD and lower than 20 % in CMD. Compared to the basalt products that have a strain between 2,20 % and 2,88 % in MD the difference is big.

When used for reinforcement purposes the material should normally not be stretched too much once it has been installed. It is typically used in projects where adjacent structures will be affected by these changes. To avoid this, the material may be preloaded to a certain strain. Another option is to choose a material with low strain.

Another important aspect for reinforcement purposes is that it is desirable to have a ductile material and not a brittle one. If the material is about to fail, it is desirable to get a warning before this happens. When a ductile material is used, the plastic behaviour will give room for this. This is not the case for brittle materials. As seen from all the valid test results the basalt products do not have the plastic behaviour that is found from other materials. When it fails, it does so instantly.

### 8.2.3 Vulnerability

A concern, especially for the EB geotextile and most likely for other geotextile based on basalt is their vulnerability to mechanical damage. This damage may be caused by granular material, careless handling or other factors that take place on the construction site or even earlier in the supply chain. As was seen for the EB geotextile the strength reduction can be immense. The reduction might be even bigger in the field than what is found during laboratory testing.

As the material is stiff and brittle it is vulnerable to bending. The products received for testing could be broken just by bending the strands. Proper coating helps to make the material more bendable. The Muster geogrid has such a coating, and compared to the RT geogrid no failure can be seen after cumbersome bending in all directions. The basalt fibers may be broken inside the coating, but this is not visible.

### 8.2.4 Physical properties

The basalt fibers have some physical properties that are studied in the preliminary project thesis that are worth to mention. However, they may be more important in other fields than geotechnical engineering. Among them are the fibers' high resistance to temperatures and ability to resist a broad spectre of pH-values.

The fact that the fibers can withstand environments with high pH-values is one of the reasons why it is popular in concrete solutions. Concrete may have pH-values between 11 and 13. This is a concern when reinforcing with steel. When reinforcing with basalt with coating it is not a problem as it withstand this environment according to Zhongyu & Guijun (2018). Acidic and alkaline environments can be found in nature as well. Some plastic materials will deteriorate in these environments. Basalt will have more suitable properties.

Zhongyu & Guijun (2018) also did research on the fibers' properties when exposed to high temperatures. The study shows that the fibers can withstand high temperatures, although the strength is reduced depending on what temperature it is prone to. Turukmane et al. (2018) state that the temperature range is between 260 and 982 °C, and that the fibers have a melting temperature of about 1 450 °C. It is categorized as non-combustible and non-exploding. For geotechnical applications this property would be of importance where the material is exposed to high temperatures, as in road constructions when in contact with fresh asphalt.

## 8.3 Evaluation of applicability

### 8.3.1 Possible applications

The thesis has focused on mechanical properties as the use of basalt products for reinforcement purposes was to be studied. As mentioned in Chapter 2.1 the applications for a geosynthetic are many. Having found the properties of the material it is clear that the material has quite good strength properties while the strain properties may be of concern. Applications where the products is prone to low strains will be of interest.

Applications could therefore be in embankments in road construction, railway construction or other fields. The forces it is exposed to is depending on where in the embankment the product is placed. It would be ideal to place it as high as possible in the embankment while the product should still serve its' function.

Construction of steep slopes is another possible application for the basalt. The forces in such a construction may be quite big. A proper design is needed if the material should be used this way. As previously mentioned the brittle behaviour and the vulnerability to damage needs to be assessed. As is the case today plastic materials will do this job in a better way than basalt ones.

The fact that the material is most likely more gentle on nature than plastic products are also an important factor to consider. When the plastic materials are installed in the ground on land in places where there is limited UV radiation, microbiological degradation and other factors that may deteriorate the products they have limited negative contribution to the ecosystems. When put in places where this is not the case they may degrade and release microplastics into the ecosystem. Research has been done on the microplastic problem, which is written about in the project thesis (Faye 2021).

One place where the product is installed on land but may be prone to such environments is when geosynthetics are used in embankments on soft soil as peat and bog. Such structures are found all around Trondheim in the network of trails in Bymarka, Estenstadmarka and others. Geosynthetics are placed on soft soil with a layer of granular material on top. Very often it is combined with a geosynthetic product that will work as separation between the different particles. To combine the basalt product, especially the geogrids, with separation products will have the potential to make a good system. The layer with granular material is worn with time, especially on the edges so that parts of the product will be exposed to the environment. The degradation will happen even faster where this is the case. If basalt products are used the effects on the ecosystem will be less harmful than they will be for plastics. The use of basalt products in a combined solution with separation products in trails could be ideal.

Such areas of applications often involves rough and uneven ground. The products used here should be flexible and easy to install. The basalt products are not very flexible compared to plastic products. Installation where the ground is very uneven may be a challenge.

Other interesting applications are marine applications and applications where the fabric will be in contact with water. Concrete mattresses is a solution used in such environments. They may be used to protect pipelines offshore from dropped objects and trawl boards. Another use could be for scour protection. This could be interesting as offshore wind often will involve pillars anchored in the seabed where the scour problem needs to be solved. Offshore wind is an emerging field where there is willingness to look at new solutions.

Erosion control of river banks may be solved with the use of geosynthetics, preferably in the form of geotextiles. When they are formed into tubes or bags that are filled with local materials they can be placed in a designed pattern to fulfill their job. The use of local materials would mean less transportation and thereby less costs and emissions. In such applications they may work both as reinforcement and for erosion purposes. This may be another possible application for the basalt products.

### 8.3.2 Environmental and health aspects

It is found that the diameter of the basalt fibers depicts whether they are unhealthy to humans and animals. As mentioned in Chapter 2 fibers with diameters less than 1,5 or as some say less than 3,5 µm will remain airborne and will be able to reach the deeper lungs. 3,5 µm would be a conservative measure. According to Mafic, who is a manufacturer, there are no known health effects from long term use or contact with fibers with diameter greater than 3,5 µm. They can not penetrate the narrow, bending passages of the human respiratory tract. They will not reach the deeper lungs. They will deposit on the surfaces of the upper respiratory system and will leave the body through normal physiological mechanisms.

It is stated by many manufacturers that the control of the production is at a high level and that the control of the fiber diameter is strict. The processed fibers may still contain a small amount of respirable fibers that may reach the deeper lungs. Therefore it is of great importance to control this. Measurements should be taken in the production. The use of ventilation and respiratory masks could be appropriate measures.

As the melting temperature of the rock material is high the melting process is quite energy demanding. This is most likely the component in the supply chain that is most harmful to the environment. What source the energy is produced from will be of importance in environmental accounts.

The transportation of the material is also a concern. Often the rock quarries are situated in another country than where the fibers are produced. The manufacturers of the finished products may also be located another place than where the fibers are produced. This leads to much transportation.

All the transportation is of concern with regards to microplastics. Andreas Elsing from Huesker stated that the transport of geosynthetics made from plastics is what emits most microplastic. It is not in the production or in installation and use that most microplastics are emitted, but in transportation when the tyres of the vehicles are worn. If this is the case, the argument to use basalt products rather than plastic products due to microplastics is greatly weakened.

### 8.3.3 Certification and specification

The work done through NorGeoSpec for Norway, Sweden, Finland, and Estonia, and in the same way through Asqual for France with certification, specification and quality control is important for development of new products and materials. When results can be compared from different laboratories their credibility and accuracy can be considered and discussed. When dealing with new materials with rather unknown properties this is crucial.

### 8.3.4 Availability and political aspects

As mentioned the products are often produced from quarries in Eastern Europe, at least for products sold on the European market. The products will often be manufactured in the same countries or neighbour countries.

For instance ReforceTech get their geogrids from a producer named Kamenny Vek. Kamenny Vek is a Russian company located outside of Moscow, Russia. Usually they get the rock material from quarries in Ukraine. The rock material is transported to Kamenny Vek's production facilities. The fibers are produced here and some finished products as well. The fibers may also be sold to other producers.

With the current situation with Russia and Ukraine in war the entire supply chain is put out of action. In the project thesis (Faye 2021) it was found that most of the development within the basalt industry has been done in Eastern European countries for the European market. The unstable political situation is a challenge. The war clearly proves why.

### 8.3.5 Commercial aspects

There is a hype on green solutions and sustainable solutions today. Every company wants to reduce their footprint. This has really been put on the agenda in the construction industry. One of the major contributors to emissions in this sector is concrete. If a company is able to provide a solution where concrete is replaced with solutions based on geosyntethics it will have a great impact on their environmental accounts. If the geosynthetics are not based on plastics but rather based on natural materials as basalt it will have an even greater impact.

Prices compared to similar solutions must be considered. It is not to be hidden that the prices decide the chosen solution in most cases. Environmental aspects alone are not weighted as much as the prices are. The literature states that the prices of basalt fibers are similar to those of glass fibers. The prices will change with time and they will have a lot to say regarding the development of the material in the industry.

# Chapter 9

# Conclusion and recommendations for further work

## 9.1 Conclusion

The big question is why basalt products should be used when plastic products work as well as they do?

The products tested and the previous results obtained shows that geotextiles and geogrids based on basalt have properties that make them both suitable and less suitable for geotechnical engineering.

Tensile testing has proven to have some challenges when testing high strength and low strain products as products based on basalt fibers. The problems are mainly related to the clamping system. The faces of the clamps, what type of clamps and the clamping pressure applied has a lot of impact on the test results. The importance of an accurate strain measurement on low strain products has also proven to be of great importance.

The tensile strength found from testing according to ISO 10319 was around 230 kN/m for the EB geotextile while the geogrids had tensile strengths approximately between 54 and 74 kN/m. The values obtained are similar to products made from plastics, especially PET.

What separates the basalt products from the plastic products is their stiff behaviour and low strain at failure. All products indicated a strain less than 3 %, which is very low. As have been seen from the test results the products are brittle. The low strain and their brittle nature is not favourable.

The creep properties obtained from creep rupture testing are fairly good. The long term creep testing indicates that the material almost does not creep at 40 % of the tensile strength. Testing of resistance to weathering and microbiological resistance shows that the material is almost unaffected when put in these environments. Permeability tests performed on the EB geotextile do not show any abnormalities.

Although the strengths and strains are found based on four (five) products they give a good picture on the material type and its' properties.

It is not found any areas of application where basalt products have any clear advantages compared to plastic materials. Applications where the products could have advantages would be when they are in contact with water in situations near river systems or in marine applications. Plastic materials will then emit microplastics that may be harmful while basalt will emit chopped fibers that most likely will not be.

In conclusion, the arguments for why basalt products should be used instead of plastic products are not obvious. Challenges related to its' low strain, brittle nature, low flexibility, related to testing, uncertain value chain, costs and pricing, and low recognition make it unattractive to invest in the material. When or if these challenges are solved, the basalt products will have its' place in geotechnical engineering. Until then polymer products will be preferred.

## 9.2 Recommendations for further work

Research and development on basalt fibers and basalt products should continue. The material has proven its' right to live in other industries than geotechnical engineering.

Fiber Reinforced Plastics (FRP) can be produced to obtain almost any properties wanted. Fibers from basalt, glass, and the ones alike can be mixed with various plastic materials in all sorts of production methods. To use the fibers in such applications may be very interesting.

Problems related to testing of high strength, low strain, and brittle materials are braking the development. Other challenges will most likely come up with development of new products. Guides on how to deal with these challenges will be of great help. For testing of basalt basalt products, a guide with known challenges and measurements to be taken to avoid them would be appreciated. Organizations like IGS, NorGeoSpec or others alike could be candidates to carry out such work.

How the material will behave and function in its' applications with time is uncertain. Field testing should be carried out to assess this. Laboratory testing and field testing will not always give the same results although the laboratory testing often wants to replicate the conditions in the field. Various factors in nature can affect the material in ways that can not be recreated in the laboratory. Life cycle analysis based on the results obtained from field testing as well as laboratory testing should be carried out.

Other areas of application should be investigated. It may be that the products have superior properties for particular tasks. The value chain and the prices of the fiber and the products should also be investigated. The prices compared to similar products will to a large extent decide the development of the material. Cost analysis should be carried out. If basalt products prove to have a clear competitive advantage on price compared to its' rivals, new areas of application will be found.

Research and development carried out will benefit from being publicly available. In this way one actor will not have to do the same mistakes as another one have already done. It is not always in a company's interest to publish their work and results. Independent organizations and foundations will have an additional responsibility in this work.

# List of Abbreviations

| | |
|---|---|
| CBF | Continuous basalt fibers |
| CMD | Cross machine direction |
| EB | EB Marine AS |
| FRP | Fiber reinforced plastics |
| MD | Machine direction |
| NTNU | Norwegian University of Science and Technology |
| PET | Polyethylene terephthalate |
| PP | Polypropylene |
| PU | Polyurethane |
| RT | ReforceTech AS |
| UTS | Ultimate tensile strength |

# List of Symbols

| | |
|---|---|
| AC | Strain for secant stiffness |
| Am | Strain at tensile strength |
| AZ | Secant |
| B | Nominal width of specimen |
| $\epsilon$ | Strain |
| $\epsilon_i$ | Strain at force i |
| F | Force |
| $F_{max}$ | Maximum force |
| $kv$ | Coefficient of permittivity |
| $n$ | Number of specimens |
| $n_s$ | Number of tensile elements |
| $N_m$ | Average number of tensile elements within 1 m width of the product |
| $\Delta R$ | Retained value in percent |
| $R_0$ | Mean value for the reference specimen |
| $R_d$ | Mean value for the damaged specimen |
| $s$ | Standard variation |
| SA | Elongation at preload |
| T | Load per unit width |
| $T_{max}$ | Tensile strength |
| V | Coefficient of variation |
| VIH50 | Velocity index for a hydraulic height difference of 50 mm |
| $v - test$ | Strain rate |
| v20 | Flow velocity at 20 °C |
| $\bar{x}$ | Mean value |

# Bibliography


[1] ASTM. *ASTM D4595 Standard Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method.* 2017.

[2] D. Bérubé & P. Saunier. "Manufacturing process of geotextiles". In: *Geotextiles.* Ed. by R. M. Koerner. Woodhead Publishing, Jan. 1, 2016.

[3] A. Cózar, F. Echevarrıa, J. I. González-Gordillo, X. Irigoien, B. Úbeda, S. Hernández-León, Á. T. Palma, S. Navarro, J. Garcıa-de-Lomas, A. Ruiz, et al. "Plastic debris in the open ocean". In: *Proceedings of the National Academy of Sciences* (2014).

[4] T. Deák & T. Czigány. "Chemical Composition and Mechanical Properties of Basalt and Glass Fibers: A Comparison". In: *Textile Research Journal* 79 (May 1, 2009).

[5] V. Dhand, G. Mittal, K. Y. Rhee, S.-J. Park & D. Hui. "A short review on basalt fiber reinforced polymer composites". In: *Composites Part B: Engineering* 73 (May 2015), pp. 166–180.

[6] R. Diederich, A. L. Backes, C. Recker, H. L. Moe & E. Balmand. *Variation in test results between laboratories from different parts of the world.* 2012.

[7] H. Faye. *Geotextiles based on basalt for erosion control and reinforcement purposes.* Dec. 2021.

[8] V. Fiore, T. Scalici, G. Di Bella & A. Valenza. "A review on basalt fibre and its composites". In: *Composites Part B: Engineering* 74 (June 1, 2015).

[9] Global Basalt Engineering. *Research surveys for basalt rocks.* URL: https://basalt.engineering/basalt_rocks (visited on 05/21/2022).

[10] C.-A. Graubner, T. Proske & S. Hofmann. *Entwicklung von basaltbewehrten Deckenplatten für den Wohnungsbau.* 2021.

[11] R. C. Hale, M. E. Seeley, M. J. La Guardia, L. Mai & E. Y. Zeng. "A Global Perspective on Microplastics". In: *Journal of Geophysical Research: Oceans* (2020).

[12] Happho. *Geogrids: Types, Applications and Advantages in Construction Industry.* June 14, 2017.

[13] A. A. Horton & S. J. Dixon. "Microplastics: An introduction to environmental transport processes". In: *WIREs Water* (2018).

[14] ISO. *ISO 13431 Geotextiles and geotextile-related products — Determination of tensile creep and creep rupture behaviour*. 1999.

[15] ISO. *ISO 12236 Geosynthetics — Static puncture test (CBR test)*. 2006.

[16] ISO. *ISO 13433 Geosynthetics — Dynamic perforation test (cone drop test)*. 2006.

[17] ISO. *ISO 10319 Geosynthetics — Wide-width tensile test*. 2015.

[18] ISO. *ISO 10722 Geosynthetics — Index test procedure for the evaluation of mechanical damage under repeated loading — Damage caused by granular material (laboratory test method)*. 2019.

[19] ISO. *ISO 12956 Geotextiles and geotextile-related products — Determination of the characteristic opening size*. 2019.

[20] R. M. Koerner. *Designing with Geosynthetics - 6Th Edition Vol. 1*. Jan. 16, 2012.

[21] K. D. Langley & Y. K. Kim. "Manufacturing nonwovens and other products using recycled fibers containing spandex". In: *Recycling in Textiles*. Ed. by Y. Wang. Jan. 1, 2006.

[22] J. Militký, V. Kovačič & J. Rubnerová. "Influence of thermal treatment on tensile failure of basalt fibers". In: *Engineering Fracture Mechanics* 69 (June 1, 2002).

[23] J. Muller-Rochholz & C. Recker. "Tensile strength and clamping of geogrids". In: *Grips, Clamps, Clamping Techniques, and Strain Measurement for Testing of Geosynthetics* (2000).

[24] NorGeoSpec. *NorGeoSpec 2012*. 2012.

[25] A. Patel. "Soil reinforcement". In: *Geotechnical Investigations and Improvement of Ground Conditions*. 2019.

[26] F. Petersen & J. A. Hubbart. "The occurrence and transport of microplastics: The state of the science". In: *Science of The Total Environment* (Mar. 1, 2021).

[27] A. Rawal, T. H. Shah & S. C. Anand. "Geotextiles in civil engineering". In: *Handbook of Technical Textiles (Second Edition)*. 2016.

[28] ReforceTech AS. *Reforcetech - About us*. May 21, 2022. URL: https://reforcetech.com/about-us/ (visited on 05/21/2022).

[29] E. Schou Jensen. *Bergarter og mineraler*. 2006.

[30] S. K. Shukla & J.-H. Yin. *Fundamentals of Geosynthetic Engineering*. 1987.

[31] R. M. Singh & G. Venkatappa Rao. *Sustainable development: Durability of natural geotextiles as erosion control product*. 2006.

[32] Standard Norge. *NS 13251 Geotekstiler og geotekstilrelaterte produkter - Krav til egenskaper ved grunnarbeider, fundamenter og støttekonstruksjoner*. 2016.

[33] R. Turukmane, S. Gulhane & A. Daberao. "Basalt - A technical fibre for civil applications". In: *Chemical Fibers International* (Mar. 1, 2018).

[34] J. K. Weddell. “Continuous Ceramic Fibres”. In: *The Journal of The Textile Institute* 81 (Jan. 1, 1990).

[35] L. Zhongyu & X. Guijun. “Resistance of basalt fibers to elevated temperatures and water or alkaline solution immersion”. In: *Polymer Composites* (July 1, 2018).

# Appendix A

# Data sheet for EB geotextile

# Basaltfasertextil 630

**basalt fiber woven textile 630**

Textil aus:
Faser: 100 % Basalt
Gesamtgewicht: 630 g/m²
Farbe: braun

woven textile:
fiber: 100 % basalt
total weight: 630 g/m²
colour: brown

## Rollenabmessungen Standard
standard roll dimensions

| | |
|---|---|
| Breite width | 1580 mm |
| Länge length | max. 500 m |
| Gewicht/Rolle weight per roll | 500 kg |

## Aufbau
construction

| | |
|---|---|
| Material material | 100 % Basaltfaser gewoben 100 % basalt fiber woven |

## Eigenschaften
specifications

| | | |
|---|---|---|
| Faserdichte filament density | 2,67 g/dm³ | |
| Schmelzpunkt melting point | 1350 °C | |
| Flächengewicht surface weight | 630 g/m² | ISO 3374:2000 |
| Breite width | 1580 mm | ISO 5025:1997 |
| Dicke thickness | 0,36 mm | ISO 4603:1993 |
| UV Stabilität UV stability | > 7 | ISO 105-B02 |

## Verpackung
packaging

Textil gerollt auf Pappkartonkern. Die Rollen sind horizontal auf einer Palette angeordnet und mit Umreifung gesichert.
Fabric rolls on cardboard tube. Rolls are arranged horizontal on a pallet with secure strapping.

Alle hier gemachten Angaben beruhen auf unseren bisherigen Erfahrungen und sind als unverbindlich zu betrachten. Die Prüfungen beruhen auf Messungen des Zulieferers an Stichproben und stellen nur eine technische Beschreibung des Produktes dar. Eine über den Wert unseres Produktes hinausgehende Haftung kann aus den vorstehenden Ausführungen nicht abgeleitet werden.

All statements made herein are based on our experienced gained to date and are to be considered without obligation. The specific values mentioned are based on measurements made by the supplier taken from random samples and are only representative for the technical description of the product. No liability exceeding the value of our product can be derived from the foregoing statements.

Stand: 2022-02
Current state: 2022-02

## Appendix B

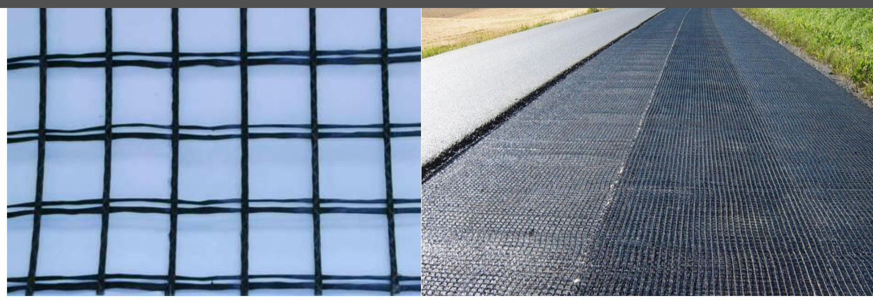
# Data sheet for RT geogrid

ReforceTech™
Creating Opportunities

PRODUCT DATA SHEET

# GeoGrid™

## HIGH PERFORMANCE FRP COMPOSITE REINFORCEMENT FOR CONCRETE



## DESCRIPTION

**Basalt** reinforcing mesh with alkali resistant coating is designed for reinforcing road, railways, and concrete applications. For road and railway, prolong the pavement lifespan by reducing the effects of reflective cracking caused by traffic loading, age hardening and temperature cycling. Pavement life between maintenance can be prolonged significantly. Basalt reinforcing mesh makes it possible to reduce thickness of asphalt pavement up to 20%.

## BENEFITS

- Higher mechanical strength and modulus, more resistive to chemical aggressive environment than E-glass mesh.
- The melting point of basalt fibres is 1450°C.
- Typical paving temperatures will not cause any loss application temperature than for synthetic material. That is especially important for north regions.
- Lower elongation before break rupture than for synthetic material.
- Easily milled using typical milling equipment.
- Does not stretch and pull as polymer meshes.
- No special equipment is required to install the reinforcement.
- Basalt mesh is environment friendly and based on naturally occurring material that is found worldwide.
- Specially developed coating provides good adhesion with concrete to improve tensile strength and increase impact resistance.
- High mechanical strength and modulus.
- High resistance to chemical aggressive environment and in particular high alkali resistance will not allow appearance of rust or corrode.
- Minimizes crack width and spread.

ReforceTech AS
Luftveien 4
NO-3440 Røyken
Norway
+47
www.Reforcetech.com

# Appendix C

# Test results from Statens Vegvesen in Oslo, Norway

# Strekkprøving av fiberduk NS-EN ISO 10319

Dato: 22.03.2022
Operatør: MTS

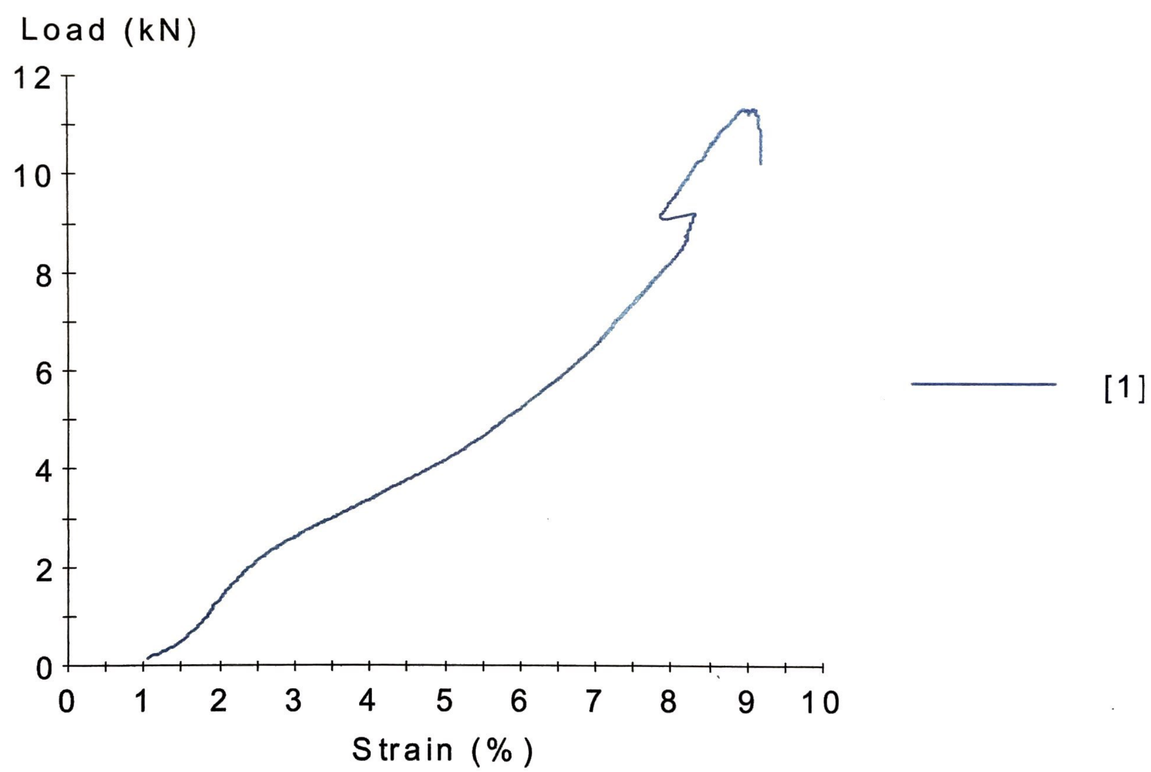
Oppdrag: Televev 70-70.mss

**Prøveinforformasjon:**

| | |
|---|---|
| 1. Typebetegnelse | Televev 70-70 |
| 2. Oppdragsgiver | Henrik Faye NTNU |

**Prøveresultater:**

| Prøvenr. | Målt vekt enkeltprøve g | Maks. kraft kN | Strekkstyrke kN/m | Tøyning ved brudd % | Energiindeks kN/m | Arealvekt g/m2 | |
|---|---|---|---|---|---|---|---|
| 1 | 13,93 | 11,33 | 56,65 | 9,0 | 2,59 | 232,17 | |
| Mean | 13,93 | 11,33 | 56,65 | 9,0 | 2,59 | 232,17 | |
| Std. Dev. | **** | **** | **** | **** | **** | **** | |



# Strekkprøving av fiberduk NS-EN ISO 10319

Dato: 22.03.2022
Operatør: MTS

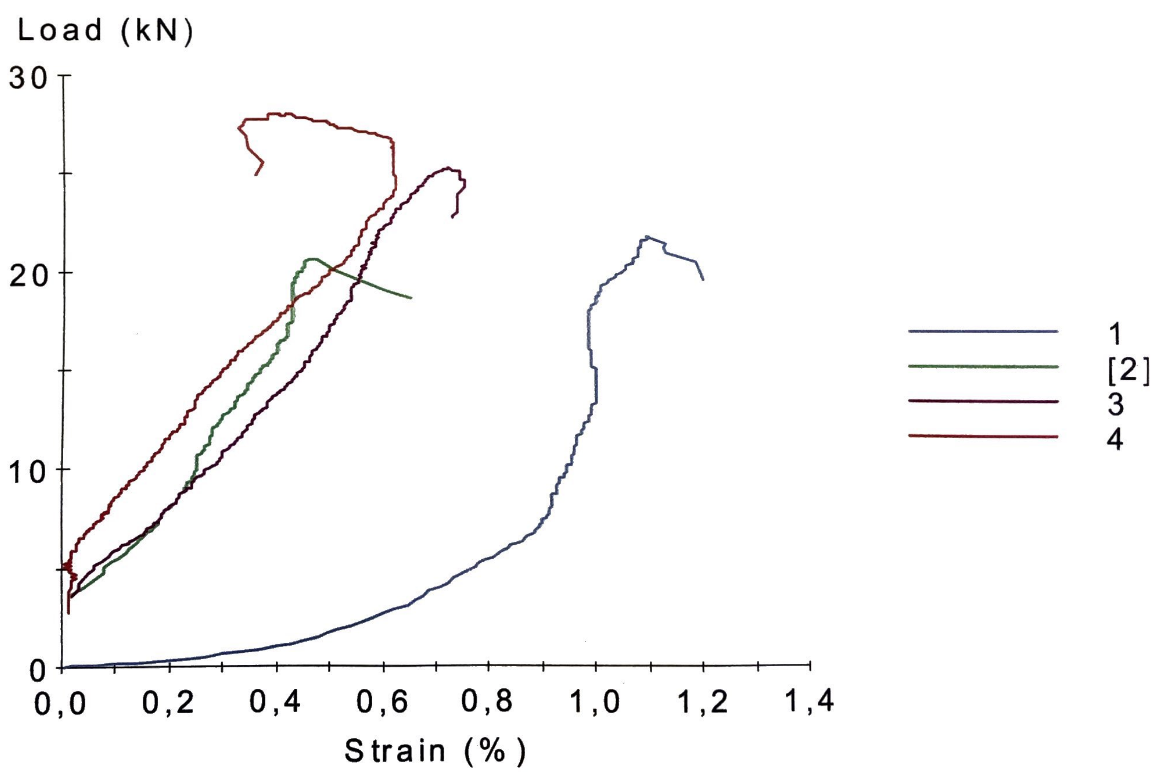
Oppdrag: Basalt EB .mss

**Prøveinforformasjon:**

| | |
|---|---|
| 1. Typebetegnelse | Basalt EB |
| 2. Oppdragsgiver | Henrik Faye NTNU |

**Prøveresultater:**

| Prøvenr. | Målt vekt enkeltprøve g | Maks. kraft kN | Strekkstyrke kN/m | Tøyning ved brudd % | Energiindeks kN/m | Arealvekt g/m2 | |
|---|---|---|---|---|---|---|---|
| 1 | 38,48 | 21,76 | 108,82 | 1,0 | 0,56 | 641,33 | |
| 2 | 38,48 | 20,62 | 103,11 | 0,5 | 0,24 | 641,33 | |
| 3 | 38,48 | 25,28 | 126,39 | 0,7 | 0,46 | 641,33 | |
| 4 | 38,48 | 28,10 | 140,48 | 0,5 | 0,33 | 641,33 | |
| Mean | 38,48 | 23,94 | 119,70 | 0,7 | 0,40 | 641,33 | |
| Std. Dev. | 0,00 | 3,41 | 17,03 | 0,3 | 0,14 | 0,00 | |



# Strekkprøving av fiberduk NS-EN ISO 10319

Dato: 22.03.2022
Operatør: MTS

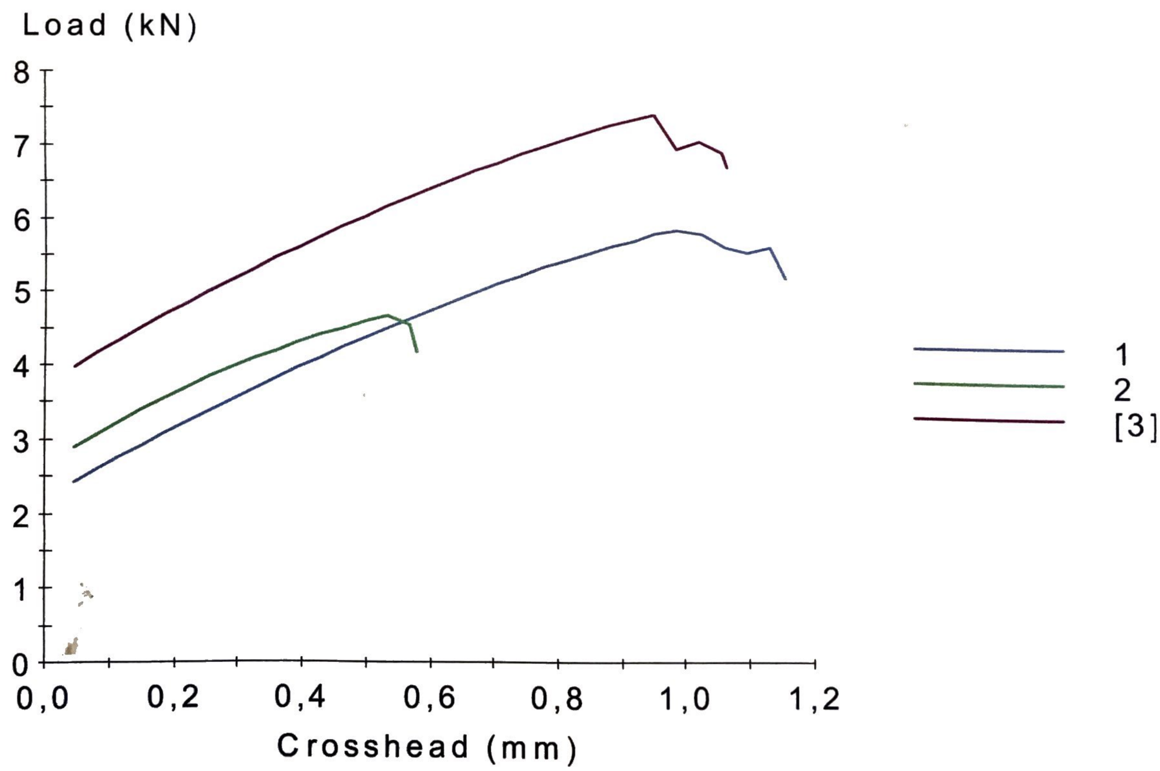
Oppdrag: Basalt RT.mss

**Prøveinforformasjon:**

| | |
|---|---|
| 1. Typebetegnelse | Basalt RT |
| 2. Oppdragsgiver | Henrik Faye NTNU |

**Prøveresultater:**

| Prøvenr. | Målt vekt enkeltprøve g | Maks. kraft kN | Strekkstyrke kN/m | Tøyning ved brudd % | Energiindeks kN/m | Arealvekt g/m2 | |
|---|---|---|---|---|---|---|---|
| 1 | 15,68 | 5,85 | 29,26 | 0,5 | 0,07 | 261,33 | |
| 2 | 15,68 | 4,65 | 23,26 | **** | **** | 261,33 | |
| 3 | 15,68 | 7,42 | 37,11 | 1,0 | 0,19 | 261,33 | |
| Mean | 15,68 | 5,97 | 29,87 | 0,7 | 0,13 | 261,33 | |
| Std. Dev. | 0,00 | 1,39 | 6,95 | 0,3 | 0,08 | 0,00 | |



# GE-TE-FLOW Statistik Report

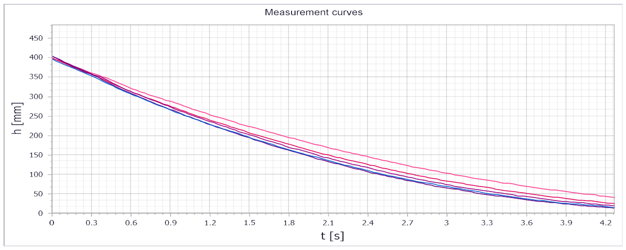
**Water permittitvity test according to DIN EN 11058-6**

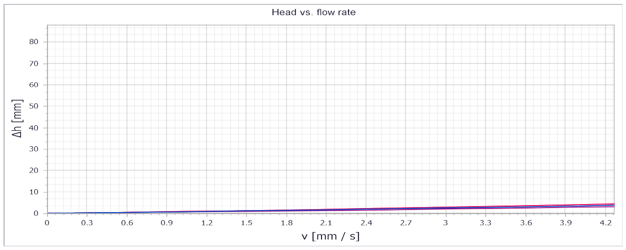
| VIH50 | |
|---|---|
| Minimum | 21.12 mm/s |
| Maximum | 26.5 mm/s |
| Average | 24.61 mm/s |
| Standard deviation | 2.21 mm/s |
| Coefficient of variation | 8.99 |

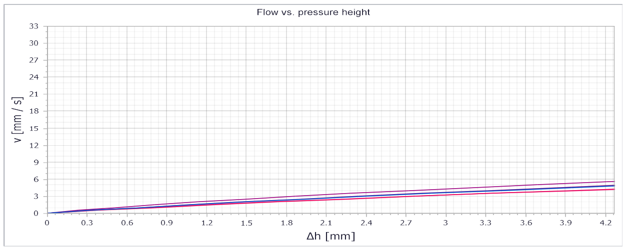
| kv (coefficent of permittivity at 20 °C) | |
|---|---|
| Minimum | 00.00017 m/s |
| Maximum | 00.00019 m/s |
| Average | 00.00018 m/s |
| Standard deviation | 00.00001 m/s |
| Coefficient of variation | 04.81792 |

| Time t required one liter (1L) | |
|---|---|
| Minimum | 10.45 s |
| Maximum | 13.12 s |
| Average | 11.34 s |
| Standard deviation | 1.1 s |
| Coefficient of variation | 9.69 |

| Date of measurement | # | Sample Name | Producer | Temp. °C | VIH50 (v20) | VIHUser | kv | Time sec/l | Sample thickness |
|---|---|---|---|---|---|---|---|---|---|
| 23.03.2022, 10:23 | 1 | 1_Wednesday, March 23, 2022 | EB Marine | 19.7°C | 21.119 mm/s | 31.371 mm/s | 0.000169 m/s | 13.12 s | 0.36 mm |
| 23.03.2022, 10:33 | 2 | 2_Wednesday, March 23, 2022 | EB Marine | 19.8°C | 23.733 mm/s | 35.79 mm/s | 0.0001899 m/s | 11.67 s | 0.36 mm |
| 23.03.2022, 10:40 | 3 | 3_Wednesday, March 23, 2022 | EB Marine | 19.8°C | 25.909 mm/s | 38.1 mm/s | 0.0001865 m/s | 10.69 s | 0.36 mm |
| 23.03.2022, 10:48 | 4 | 4_Wednesday, March 23, 2022 | EB Marine | 19.9°C | 26.502 mm/s | 39.809 mm/s | 0.0001908 m/s | 10.45 s | 0.36 mm |
| 23.03.2022, 11:01 | 5 | 5_Wednesday, March 23, 2022 | EB Marine | 20°C | 25.768 mm/s | 38.674 mm/s | 0.0001855 m/s | 10.75 s | 0.36 mm |


Measurement curves
h [mm]
t [s]


Head vs. flow rate
Δh [mm]
v [mm / s]


Flow vs. pressure height
v [mm / s]
Δh [mm]

# Appendix D

# Test results from KIWA in Greven, Germany

## Wide-width tensile test
# DIN EN ISO 10319 (09.2015)

| | | | |
|---|---|---|---|
| **Test Report No.** | **: 1.1/xxxxx/xxxx.0.1-2022** | **Material** | **: EB Basalt** |
| **Company** | **: NTNU** | **Test direction** | **: MD** |
| **Operator** | **: jt** | **Test condition** | **: dry** |
| **Date** | **: 27.04.2022** | | |

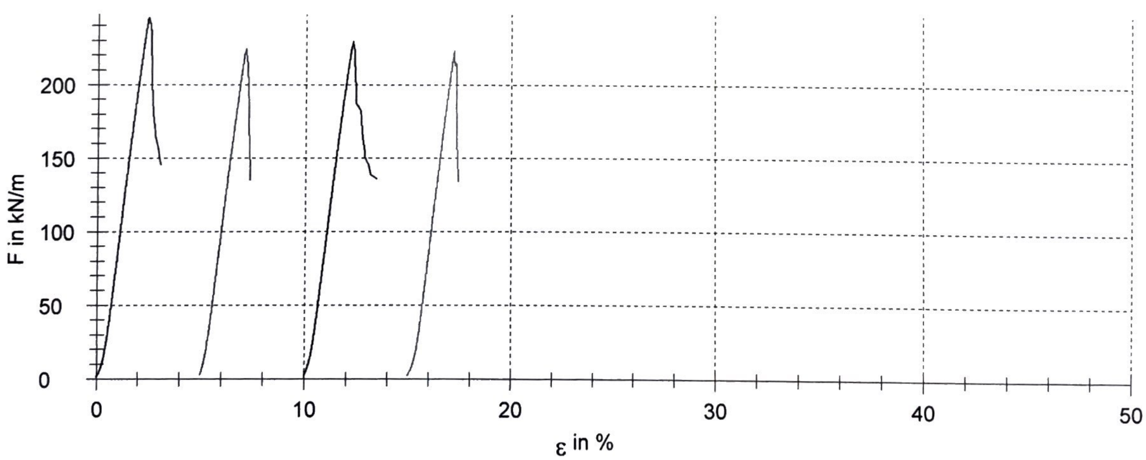
## Test parameters

| | | | |
|---|---|---|---|
| Climate | : 21°C / 34% rel. humidity | Specimen grips | : VAS V.600.HY.HY.1 (200mm x 480mm) |
| Machine | : Zwick Z600 | | |
| Load cell | : 600 kN | Specimen width | : 200,0 mm |
| Extensometer (path) | : Video | LE | : 100,0 mm |
| | | Pre load | : 490 N |

## Results

| Nr | Fm N | Fm kN/m | Am % | F at 0,5% kN/m | F at 1% kN/m | F at 2% kN/m | t-Fmax s |
|---|---|---|---|---|---|---|---|
| 1 | 49130 | 245,65 | 2,44 | 27,01 | 83,77 | 202,16 | 23,03 |
| 2 | 44891 | 224,46 | 2,12 | 41,69 | 102,70 | 216,40 | 31,54 |
| 3 | 45845 | 229,23 | 2,27 | 33,57 | 92,09 | 205,72 | 32,50 |
| 4 | 44592 | 222,96 | 2,21 | 27,57 | 85,50 | 202,62 | 31,26 |

## Series graphics




## Statistics

| Serie n = 4 | Fm N | Fm kN/m | Am % | F at 0,5% kN/m | F at 1% kN/m | F at 2% kN/m | t-Fmax s |
|---|---|---|---|---|---|---|---|
| $\bar{x}$ | 46115 | 230,57 | 2,26 | 32,46 | 91,02 | 206,73 | 29,58 |
| s | 2080 | 10,40 | 0,13 | 6,83 | 8,57 | 6,64 | 4,40 |
| ν [%] | 4,51 | 4,51 | 5,95 | 21,05 | 9,42 | 3,21 | 14,88 |

**Remarks : -**

## Wide-width tensile test
# DIN EN ISO 10319 (09.2015)

| | | | |
|---|---|---|---|
| **Test Report No.** | **: 1.1/xxxxx/xxxx.0.1-2022** | **Material** | **: EB Basalt** |
| **Company** | **: NTNU** | **Test direction** | **: MD** |
| **Operator** | **: jt** | **Test condition** | **: dry** |
| **Date** | **: 27.04.2022** | | |

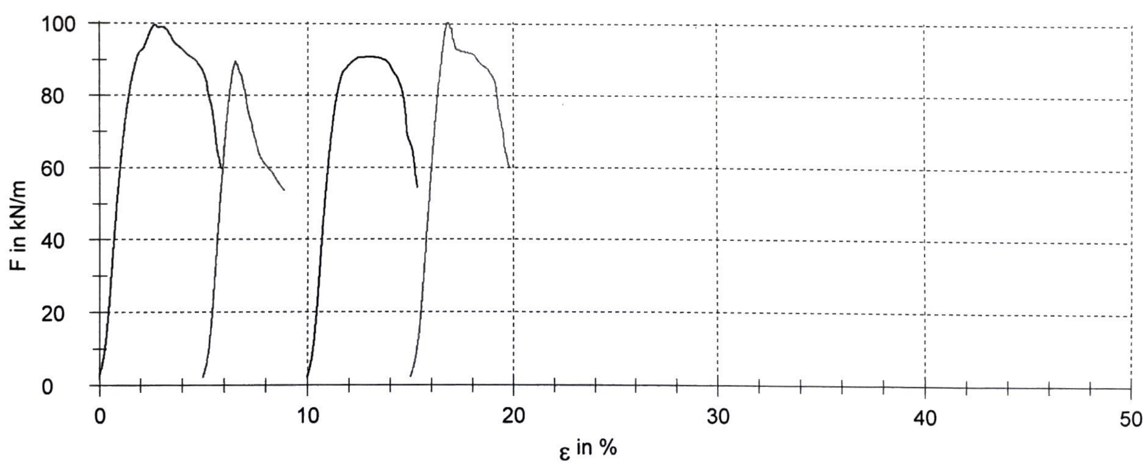
## Test parameters

| | | | |
|---|---|---|---|
| Climate | : 21°C / 34% rel. humidity | Specimen grips | : VAS V.600.HY.HY.1 (200mm x 480mm) |
| Machine | : Zwick Z600 | Specimen width | : 200,0 mm |
| Load cell | : 600 kN | LE | : 100,0 mm |
| Extensometer (path) | : Video | Pre load | : 490 N |

## Results

| Nr | Fm<br>N | Fm<br>kN/m | Am<br>% | F at 0,5%<br>kN/m | F at 1%<br>kN/m | F at 2%<br>kN/m | t-Fmax<br>s |
|---|---|---|---|---|---|---|---|
| 1 | 19933 | 99,66 | 2,72 | 23,00 | 58,98 | 92,37 | 18,39 |
| 2 | 17916 | 89,58 | 1,55 | 24,55 | 65,23 | - | 17,64 |
| 3 | 18193 | 90,97 | 2,99 | 24,31 | 61,48 | 88,73 | 17,87 |
| 4 | 20098 | 100,49 | 1,79 | 20,12 | 59,61 | - | 17,68 |

## Series graphics




## Statistics

| Serie<br>n = 4 | Fm<br>N | Fm<br>kN/m | Am<br>% | F at 0,5%<br>kN/m | F at 1%<br>kN/m | F at 2%<br>kN/m | t-Fmax<br>s |
|---|---|---|---|---|---|---|---|
| x̄ | 19035 | 95,18 | 2,26 | 22,99 | 61,32 | 90,55 | 17,89 |
| s | 1140 | 5,70 | 0,70 | 2,03 | 2,81 | 2,57 | 0,34 |
| ν [%] | 5,99 | 5,99 | 31,01 | 8,83 | 4,58 | 2,84 | 1,93 |

**Remarks : -**

## Wide-width tensile test
# DIN EN ISO 10319 (09.2015)

| | | | |
|---|---|---|---|
| **Test Report No.** | **: 1.1/xxxxx/xxxx.0.1-2022** | **Material** | **: RF Basalt** |
| **Company** | **: xxxx** | **Test direction** | **: MD** |
| **Operator** | **: jt** | **Test condition** | **: dry** |
| **Date** | **: 27.04.2022** | | |

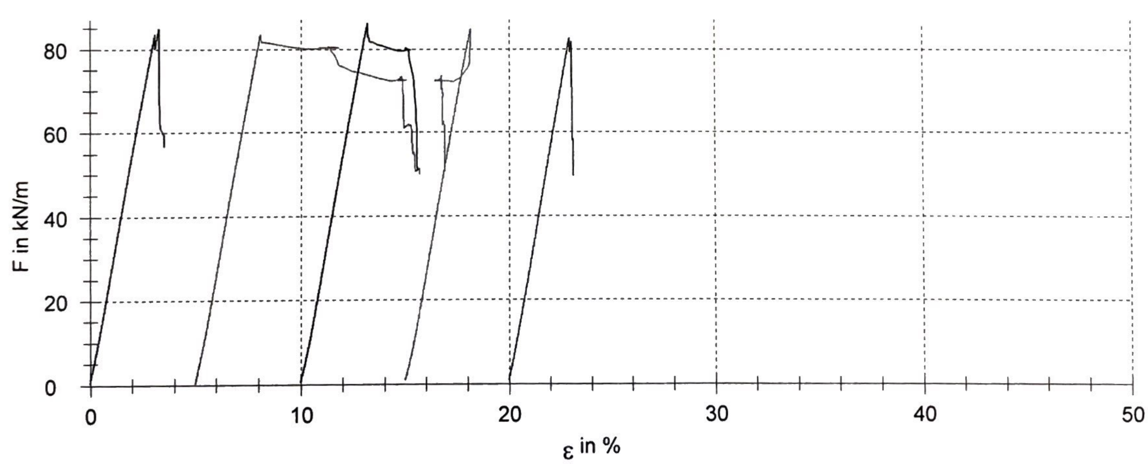
## Test parameters

| | | | |
|---|---|---|---|
| Climate | : 21°C / 34% rel. humidity | Specimen width | : 236,3 mm |
| Machine | : Zwick Z600 | Test strands | : 7 |
| Load cell | : 600 kN | Strands / m | : 29,6 |
| Extensometer (path) | : Video | LE | : 100,0 mm |
| Specimen grips | : VAS V.600.HY.HY.1 (200mm x 480mm) | Pre load | : 200 N |

## Results

| Nr | Fm N | Fm kN/m | Am % | F at 0,5% kN/m | F at 1% kN/m | F at 2% kN/m | t-Fmax s |
|---|---|---|---|---|---|---|---|
| 1 | 20063 | 84,90 | 3,28 | 12,49 | 26,16 | 54,25 | 31,90 |
| 2 | 19726 | 83,48 | 3,08 | 11,94 | 25,68 | 54,18 | 29,96 |
| 3 | 20400 | 86,33 | 3,18 | 11,97 | 25,85 | 54,44 | 31,02 |
| 4 | 20064 | 84,91 | 3,16 | 11,93 | 25,94 | 54,53 | 31,06 |
| 5 | 19547 | 82,72 | 2,95 | 13,23 | 26,89 | 55,88 | 29,04 |

## Series graphics




## Statistics

| Serie n = 5 | Fm N | Fm kN/m | Am % | F at 0,5% kN/m | F at 1% kN/m | F at 2% kN/m | t-Fmax s |
|---|---|---|---|---|---|---|---|
| $\bar{x}$ | 19960 | 84,47 | 3,13 | 12,31 | 26,10 | 54,65 | 30,60 |
| s | 332 | 1,40 | 0,13 | 0,56 | 0,47 | 0,70 | 1,11 |
| ν [%] | 1,66 | 1,66 | 4,01 | 4,59 | 1,81 | 1,28 | 3,63 |

**Remarks : -**

## Wide-width tensile test

# DIN EN ISO 10319 (09.2015)

| | | | |
|---|---|---|---|
| **Test Report No.** | **: 1.1/xxxxx/xxxx.0.1-2022** | **Material** | **: RF Basalt** |
| **Company** | **: NTNU** | **Test direction** | **: MD** |
| **Operator** | **: jt** | **Test condition** | **: dry** |
| **Date** | **: 27.04.2022** | | |

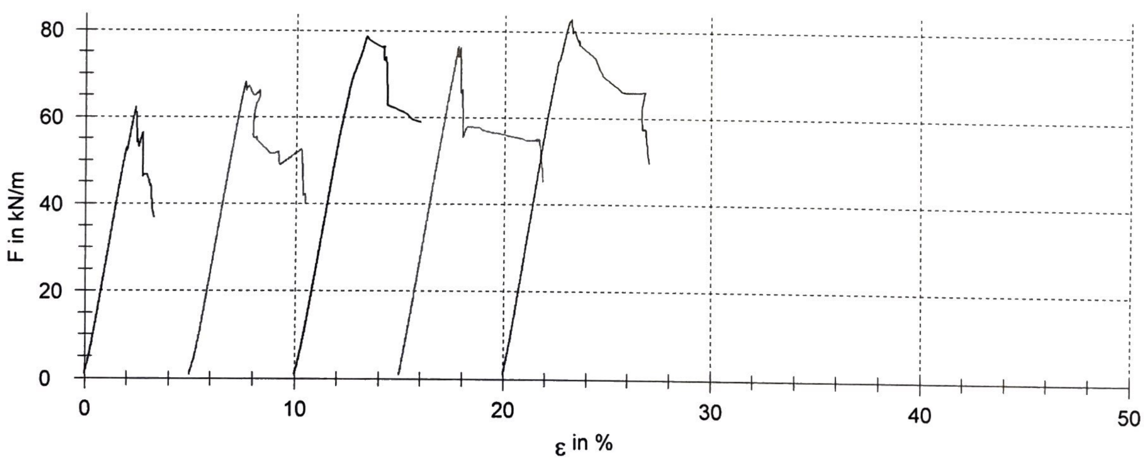
## Test parameters

| | | | |
|---|---|---|---|
| Climate | : 21°C / 34% rel. humidity | Specimen width | : 236,3 mm |
| Machine | : Zwick Z600 | Test strands | : 7 |
| Load cell | : 600 kN | Strands / m | : 29,6 |
| Extensometer (path) | : Video | LE | : 100,0 mm |
| Specimen grips | : VAS V.600.HY.HY.1 (200mm x 480mm) | Pre load | : 200 N |

## Results

| Nr | Fm N | Fm kN/m | Am % | F at 0,5% kN/m | F at 1% kN/m | F at 2% kN/m | t-Fmax s |
|---|---|---|---|---|---|---|---|
| 1 | 14703 | 62,22 | 2,42 | 12,42 | 26,19 | 52,30 | 23,40 |
| 2 | 16097 | 68,12 | 2,61 | 10,93 | 24,83 | 52,91 | 24,43 |
| 3 | 18566 | 78,57 | 3,36 | 12,04 | 25,68 | 53,74 | 28,70 |
| 4 | 18060 | 76,43 | 2,77 | 14,16 | 28,07 | 56,23 | 26,89 |
| 5 | 19599 | 82,94 | 3,27 | 13,61 | 27,99 | 56,86 | 29,97 |

## Series graphics




## Statistics

| Serie n = 5 | Fm N | Fm kN/m | Am % | F at 0,5% kN/m | F at 1% kN/m | F at 2% kN/m | t-Fmax s |
|---|---|---|---|---|---|---|---|
| $\bar{x}$ | 17405 | 73,66 | 2,88 | 12,63 | 26,55 | 54,41 | 26,68 |
| s | 1975 | 8,36 | 0,41 | 1,28 | 1,43 | 2,03 | 2,77 |
| ν [%] | 11,35 | 11,35 | 14,35 | 10,17 | 5,40 | 3,73 | 10,40 |

**Remarks : -**

## Appendix E

# Previous test results from Huesker in Gescher, Germany

# Grid-tensile test
## Test No : P0921/115

50/50 < 2 €/m²

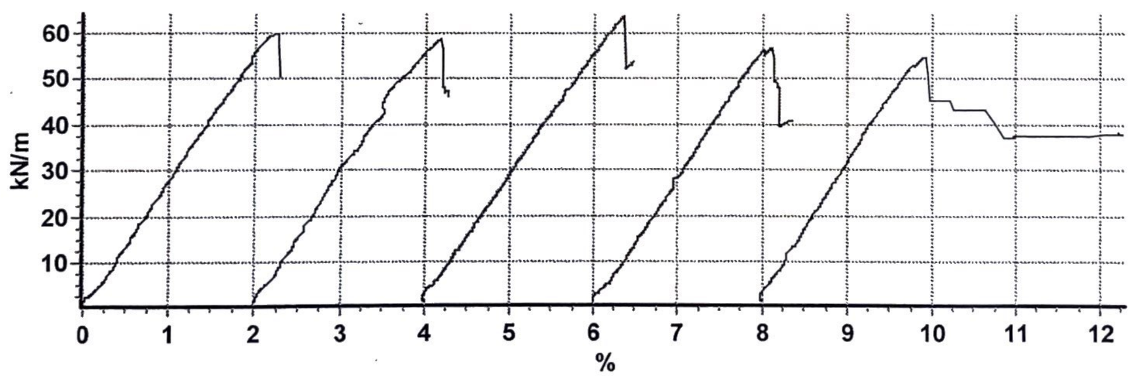
**Test Date : 09.03.2009** **Article-No.: Muster 08/02b**

| | | | | | |
|---|---|---|---|---|---|
| I-Order/Warp No: | : 29096/1 | Calcul. | : 0,860 | Thr./cm |
| Weight g/m² | : 445 | Threads/specimen | : 20,000 | |
| Thickness mm | : | Bundles/specimen | : 5,000 | |
| Width cm | : 520 521 | AP-test width | : 200,000 | mm |
| Test norm | : DIN EN ISO 10 319 6'96 | Initial load | : 13,5 | daN |

| | | | |
|---|---|---|---|
| date of receipt of the specimen | : 6.3.09 | | |
| Method of sampling | : DIN EN ISO 9862 | F1 = Force at | : 1 % |
| Condition of specimen | : dry | F2 = Force at | : 1,5 % |
| Type of testing machine | : Inspect 600 | F3 = Force at | : 2 % |
| Type of clamps | : hydraulic clamps | ε1 = Extension at | : 40 kN/m |
| conditioning | : ISO 554 20°C/65% | | |

### Test direction : MD

| No. | specimen daN | F-max kN/m | ε -max % | F1 kN/m | F2 kN/m | F3 kN/m | ε1 % | meas.-le. mm | Test speed %/Min | comment |
|---|---|---|---|---|---|---|---|---|---|---|
| 01 | 1395,8 | 60,0 | 2,2 | 28,2 | 42,4 | 56,2 | 1,4 | 58,1 | 15,2 | |
| 02 | 1361,6 | 58,6 | 2,2 | 30,4 | 41,9 | 55,6 | 1,4 | 60,5 | 18,2 | |
| 03 | 1486,4 | 63,9 | 2,4 | 29,1 | 42,7 | 55,7 | 1,4 | 54,0 | 17,6 | |
| 04 | 1315,9 | 56,6 | 2,1 | 28,3 | 42,1 | 55,8 | 1,4 | 53,3 | 17,4 | |
| 05 | 1270,4 | 54,6 | 1,9 | 31,5 | 45,7 | 45,1 | 1,3 | 58,5 | 16,4 | |




### Statistic :

| n=0 | specimen daN | **F-max kN/m** | ε -max % | F1 kN/m | F2 kN/m | F3 kN/m | ε1 % | meas.-le. mm | Test speed %/Min |
|---|---|---|---|---|---|---|---|---|---|
| $\bar{x}$ | 1366,02 | **58,74** | 2,16 | 29,5 | 42,96 | 53,68 | 1,38 | 56,88 | 16,96 |
| s | 82,239 | **3,534** | 0,182 | 1,423 | 1,561 | 4,802 | 0,045 | 3,095 | 1,178 |
| V | 6,02 | **6,016** | 8,41 | 4,824 | 3,635 | 8,945 | 3,241 | 5,442 | 6,947 |

Modification of procedure:

Information:

**The test results only relate to the above material.**



**date :** 9.3.09 **Test executed by:** B.Finnah **Laboratory manager** J. Mustor
(B.Finnah)

HUESKER Germany



HUESKER Synthetic GmbH · Fabrikstraße 13 – 15 · D-48712 Gescher
Phone + 49 (0) 25 42/701-0 · Fax + 49 (0) 25 42/701-499

Deutscher Akkreditierungs Rat
DAP-P-03.226-00-98-00

**HUESKER**
TestLaboratory

## Grid-tensile test
## Test No : P0921/115

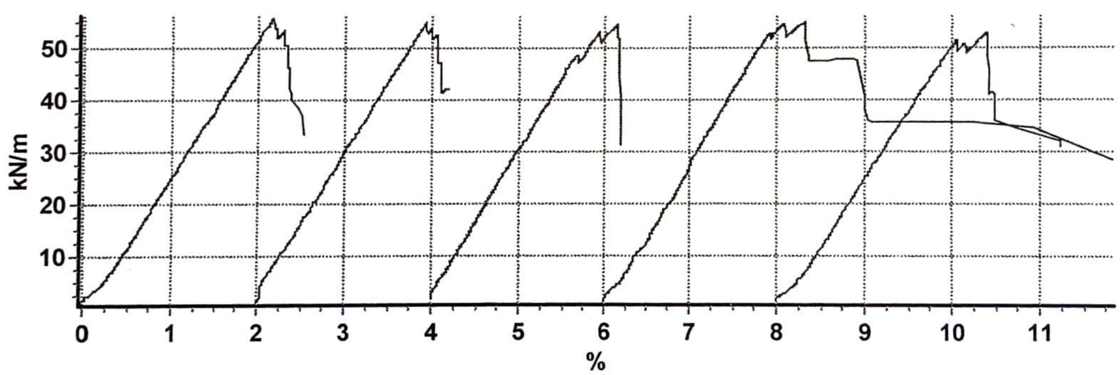
**Test Date : 09.03.2009** **Article-No.: Muster 08/02b**

| | | | | |
|---|---|---|---|---|
| I-Order/Warp No: | : 29096/1 | Calcul. | : 0,850 | Thr./cm |
| Weight g/m² | : 445 | Threads/specimen | : 20,000 | |
| Thickness mm | : | Bundles/specimen | : 5,000 | |
| Width cm | : 520 521 | AP-test width | : 200,000 | mm |
| Test norm | : DIN EN ISO 10 319 6'96 | Initial load | : 13 | daN |

| | | | |
|---|---|---|---|
| date of receipt of the specimen | : 6.3.09 | | |
| Method of sampling | : DIN EN ISO 9862 | F1 = Force at | : 1 % |
| Condition of specimen | : dry | F2 = Force at | : 1,5 % |
| Type of testing machine | : Inspect 600 | F3 = Force at | : 2 % |
| Type of clamps | : hydraulic clamps | ε1 = Extension at | : 40 kN/m |
| conditioning | : ISO 554 20°C/65% | | |

**Test direction : CMD**

| No. | specimen daN | F-max kN/m | ε -max % | F1 kN/m | F2 kN/m | F3 kN/m | ε1 % | meas.-le. mm | Test speed %/Min | comment |
|---|---|---|---|---|---|---|---|---|---|---|
| 01 | 1316,0 | 55,9 | 2,2 | 25,1 | 38,1 | 51,7 | 1,6 | 61,0 | 19,9 | |
| 02 | 1289,3 | 54,8 | 1,9 | 29,8 | 43,2 | 52,2 | 1,4 | 61,8 | 17,9 | |
| 03 | 1279,4 | 54,4 | 2,2 | 30,4 | 43,9 | 51,9 | 1,4 | 57,4 | 18,1 | |
| 04 | 1287,3 | 54,7 | 2,3 | 26,9 | 41,8 | 53,1 | 1,4 | 61,1 | 19,5 | |
| 05 | 1242,7 | 52,8 | 2,4 | 24,8 | 37,3 | 49,7 | 1,6 | 69,7 | 21,0 | |




**Statistic :**

| n=0 | specimen daN | **F-max kN/m** | ε -max % | F1 kN/m | F2 kN/m | F3 kN/m | ε1 % | meas.-le. mm | Test speed %/Min |
|---|---|---|---|---|---|---|---|---|---|
| $\overline{x}$ | 1282,94 | **54,52** | 2,2 | 27,4 | 40,86 | 51,72 | 1,48 | 62,2 | 19,28 |
| s | 26,383 | **1,117** | 0,187 | 2,601 | 2,995 | 1,25 | 0,11 | 4,53 | 1,293 |
| V | 2,056 | **2,048** | 8,504 | 9,493 | 7,331 | 2,416 | 7,402 | 7,284 | 6,707 |

Modification of procedure:

Information:

**The test results only relate to the above material.**

**This test report may not be reproduced in part without permission of the lab.**

**date** :9.3.09 **Test executed by:**[signature] **Laboratory manager**[signature]
(B.Finnah)

HUESKER



HUESKER Synthetic GmbH · Fabrikstraße 13 – 15 · D-48712 Gescher
Phone + 49 (0) 25 42/701-0 · Fax + 49 (0) 25 42/701-499

kge0115m

## Appendix F

# Previous test results from KIWA in Greven, Germany

kiwa
Partner for progress

**Kiwa GmbH**
TBU
Gutenbergstraße 29
48268 Greven

Tel. +49 (0)2571 9872 0
Fax +49 (0)2571 9872 99
infokiwagreven@kiwa.de
www.kiwa.de

# Prüfbericht Nr. 1.6 / 17810 / 0413.0.1-2012

**Allgemeines** – General

– created on
Erstellt am : 17.06.2015

Antragsteller : **HUESKER Synthetic GmbH**
**Fabrikstraße 13-15**
**48712 Gescher, DEUTSCHLAND**

coated basalt geogrid
Material : beschichtetes Basalt-Geogitter (schwarz)
**Fortrac R 50/50-40 B**
(Bezeichnung des Antragstellers)

Auftrag vom : 15.03.2012

Probeneingang : 15.03.2012

| Prüfungen | Norm | Ausgabe | Ergebnisse als Anlage Nr. |
|---|---|---|---|
| 1. Zugversuch am breiten Streifen (Tensile test on a wide strip) | DIN EN ISO 10319 | 10.2008 | A1 - A5 |
| 2. Zeitstandbruchverhalten (creep rupture behaviour) | DIN EN ISO 13431 | 11.1999 | A6 - A11 |

Die Prüfwerte gelten ausschließlich für die verwendeten Messproben.
Der Zeitpunkt der Prüfung ist dem jeweiligen Anlagenblatt zu entnehmen.
Prüfwerte werden - soweit Normen dies vorschreiben - mit der diesen Normen entsprechenden Genauigkeit angegeben. Für statistische Auswertungen werden alle gemessenen Stellen verwendet.

Dieser Prüfbericht umfasst 3 Seiten und 11 Anlage/-en (Seite/-en A1 - A11, grundsätzlich in englischer Sprache).
Der Prüfbericht darf nicht in Teilen veröffentlicht werden.

kiwa
Partner for progress

## Prüfbericht Nr. 1.6/ 17810 / 0413.0.1-2012 Seite 2

### Kurzfassung der Ergebnisse – summary of results

Datum/Aktenzeichen: 17.06.2015 / cs

Antragsteller : **HUESKER Synthetic GmbH , Fabrikstraße 13-15 , 48712 Gescher, DEUTSCHLAND**

Material : beschichtetes Basalt-Geogitter (schwarz)
**Fortrac R 50/50-40 B**
(Bezeichnung des Antragstellers)

| Prüfung | Norm | Einheit | Mittelwert $\bar{x}$ | Standard-abweichung s | Variations-koeffizient v in % |
|---|---|---|---|---|---|
| **Zugversuch am breiten Streifen** | **DIN EN ISO 10319 10.2008** | | | | |
| Höchstzugkraft - Max tensile force MD | | kN/m | 65,4 | 1,43 | 2,2 |
| Höchstzugkraftdehnung - Elongation MD | | % | 2,3 | 0,23 | 9,8 |
| Bemerkung: Prüfung am Einzelstrang, Klemmbereich des Geogitters mit Pappe geschützt – Note: Test on a single strand, clamps protected with cardboard | | | | | |
| **Zugversuch am breiten Streifen** | **DIN EN ISO 10319 10.2008** | | | | |
| Höchstzugkraft MD | | kN/m | 70,5 | 1,65 | 2,3 |
| Höchstzugkraftdehnung MD | | % | 2,3 | 0,16 | 7,1 |
| Bemerkung: Prüfung am Einzelstrang, Klemmbereich des Geogitters mit Vliesstoff geschützt – Fleece | | | | | |
| **Zugversuch am breiten Streifen** | **DIN EN ISO 10319 10.2008** | | | | |
| Höchstzugkraft MD | | kN/m | 69,7 | 1,94 | 2,8 |
| Höchstzugkraftdehnung MD | | % | 2,3 | 0,18 | 8,0 |
| Bemerkung: Prüfung am Einzelstrang, Klemmbereich des Geogitters mit PU-Schaum (Bauschaum) geschützt – PU foam | | | | | |
| **Zugversuch am breiten Streifen** | **DIN EN ISO 10319 10.2008** | | | | |
| Höchstzugkraft MD | | kN/m | 67,4 | 2,87 | 4,3 |
| Höchstzugkraftdehnung MD | | % | 2,1 | 0,09 | 4,5 |
| Bemerkung: Prüfung am Einzelstrang, Klemmbereich des Geogitters mit fest erhärtendem Epoxidharz geschützt – Solid hardening epoxy resin | | | | | |
| **Zugversuch am breiten Streifen** | **DIN EN ISO 10319 10.2008** | | | | |
| Höchstzugkraft MD | | kN/m | 67,0 | 4,23 | 6,3 |
| Höchstzugkraftdehnung MD | | % | 2,1 | 0,19 | 9,2 |
| Bemerkung: Prüfung am Einzelstrang, Klemmbereich des Geogitters mit weich erhärtendem Epoxidharz geschützt – Soft-setting epoxy resin | | | | | |

Fortsetzung auf Seite 3

## Prüfbericht Nr. 1.6/17810/0413.0.1-2012 Seite 3

### Kurzfassung der Ergebnisse

Datum/Aktenzeichen: 17.06.2015 / cs

Antragsteller : **HUESKER Synthetic GmbH , Fabrikstraße 13-15 , 48712 Gescher, DEUTSCHLAND**

Material : beschichtetes Basalt-Geogitter (schwarz)
**Fortrac R 50/50-40 B**
(Bezeichnung des Antragstellers)

(Residual strength after $10^3$ h (extrapolated))

| Prüfung | Norm | Einheit | Restfestigkeit nach $10^3$ h (extrapoliert) |
|---|---|---|---|
| **Bestimmung des Zeitstandbruchverhaltens** (- Determination of creep behaviour)<br>Lineare Regression | **DIN EN ISO 13431 11.1999** | % | 51,7 |

Bemerkung: Prüfung am Einzelstrang, Klemmbereich des Geogitters mit Vliesstoff geschützt (- Test on a single strand, clamps protected with non-woven fabric)

| Prüfung | Norm | Einheit | Restfestigkeit nach $10^3$ h (extrapoliert) |
|---|---|---|---|
| **Bestimmung des Zeitstandbruchverhaltens**<br>Lineare Regression | **DIN EN ISO 13431 11.1999** | % | 57,0 |

Bemerkung: Prüfung am Einzelstrang, Klemmbereich des Geogitters mit PU-Schaum (Bauschaum) geschützt (- Clamping area protected with PU foam)

| Prüfung | Norm | Einheit | Restfestigkeit nach $10^3$ h (extrapoliert) |
|---|---|---|---|
| **Bestimmung des Zeitstandbruchverhaltens**<br>Lineare Regression | **DIN EN ISO 13431 11.1999** | % | 55,3 |

Bemerkung: Prüfung am Einzelstrang, Klemmbereich des Geogitters mit fest erhärtendem Epoxidharz geschützt (- Clamps protected with hard setting epoxy)

Kiwa GmbH
kiwa

i.A. Dipl.-Ing. (FH) Christoph Staubermann
(Leiter Prüfstelle)

i.A. Matthias Käsekamp, B. Eng.
(Mitarbeiter Prüfstelle)



tBU
Geschäftsführer:
Dr. Ulrich Ellinghaus,
Dr. Roland Hüttl
Amtsgericht Hamburg
HRB 130568
St.Nr.: 47/736/00886

## Wide-width tensile test
# DIN EN ISO 10319 (10.2008)

| | | | |
|---|---|---|---|
| Test Report No. | : 1.6/17810/0413.0.1-2012 | Material | : Fortrac R 50/50-40 B |
| Company | : HUESKER Synthetic GmbH | Test direction | : MD |
| Operator | : de | Test condition | : dry |
| Date | : 28.03.2012 | | |

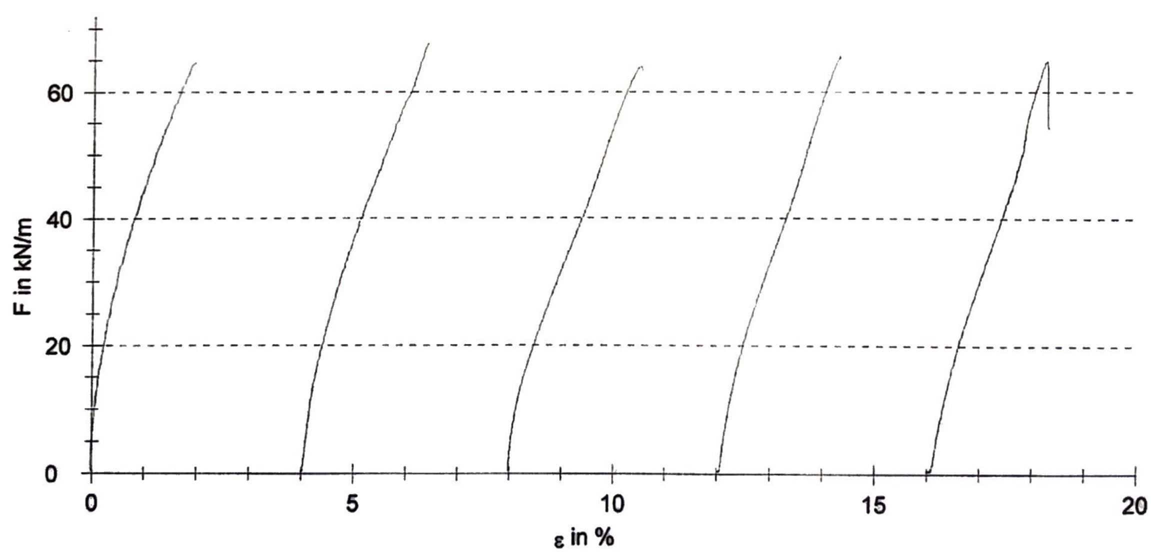
## Test parameters

| | | | |
|---|---|---|---|
| Climate | : 22 °C /42 % r. humidity | Specimen width b0 | : 46 mm |
| Machine | : Zwick Z250 | Teststrands | : 1 |
| Load cell | : 250 kN | Strands/ m | : 21,7 |
| Extensometer (path) | : Video | LE | : 100 mm |
| Specimen grips | : Demgen M250 | Pre-load | : 30 N |

## Results

| Nr | Fm N | Fm kN/m | Am % | F at 0,5% kN/m | F at 1% kN/m | F at 1,5% kN/m | Strain at nom. load % | v-test %/min |
|---|---|---|---|---|---|---|---|---|
| 1 | 2975 | 64,68 | 1,92 | 31,27 | 45,23 | 56,89 | 0,80 | 28,50 |
| 2 | 3113 | 67,68 | 2,39 | 23,57 | 37,41 | 48,55 | 1,12 | 26,55 |
| 3 | 2942 | 63,96 | 2,52 | 20,66 | 31,72 | 42,19 | 1,40 | 21,11 |
| 4 | 3019 | 65,63 | 2,35 | 20,19 | 32,73 | 44,52 | 1,32 | 20,04 |
| 5 | 2982 | 64,82 | 2,29 | 16,83 | 29,87 | 41,72 | 1,43 | 20,65 |

## Series graphics




## Statistics

| Serie n = 5 | Fm N | Fm kN/m | Am % | F at 0,5% kN/m | F at 1% kN/m | F at 1,5% kN/m | Strain at nom. load % | v-test %/min |
|---|---|---|---|---|---|---|---|---|
| $\bar{x}$ | 3006 | 65,35 | 2,29 | 22,51 | 35,39 | 46,77 | 1,21 | 23,37 |
| s | 66 | 1,43 | 0,23 | 5,45 | 6,16 | 6,27 | 0,26 | 3,87 |
| v | 2,19 | 2,19 | 9,83 | 24,22 | 17,41 | 13,40 | 21,59 | 16,57 |

**Note: Clamping area of grid protected with cardboard**

## Wide-width tensile test

# DIN EN ISO 10319 (10.2008)

**Test Report No.** : 1.6/17810/0413.0.1-2012
**Company** : HUESKER Synthetic GmbH
**Operator** : de
**Date** : 28.03.2012

**Material** : Fortrac R 50/50-40 B
**Test direction** : MD
**Test condition** : dry

## Test parameters

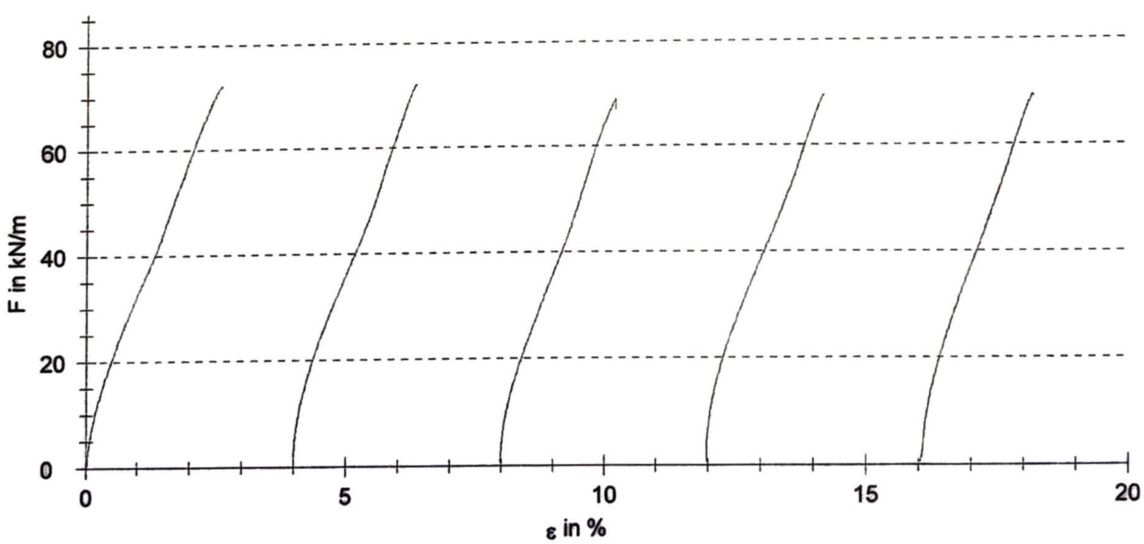
Climate : 22 °C /42 % r. humidity
Machine : Zwick Z250
Load cell : 250 kN
Extensometer (path): Video
Specimen grips : Demgen M250

Specimen width b0 : 46 mm
Teststrands : 1
Strands/ m : 21,7
LE : 100 mm
Pre-load : 30 N

## Results

| Nr | Fm N | Fm kN/m | Am % | F at 0,5% kN/m | F at 1% kN/m | F at 1,5% kN/m | Strain at nom. load % | v-test %/min |
|---|---|---|---|---|---|---|---|---|
| 1 | 3326 | 72,31 | 2,58 | 20,22 | 32,73 | 44,86 | 1,32 | 19,87 |
| 2 | 3324 | 72,26 | 2,33 | 23,91 | 35,97 | 48,31 | 1,17 | 18,89 |
| 3 | 3173 | 68,97 | 2,22 | 22,75 | 35,49 | 49,12 | 1,18 | 18,08 |
| 4 | 3201 | 69,59 | 2,22 | 26,16 | 38,08 | 49,73 | 1,09 | 21,31 |
| 5 | 3190 | 69,35 | 2,18 | 23,19 | 37,20 | 50,12 | 1,12 | 19,37 |

## Series graphics




## Statistics

| Serie n = 5 | Fm N | Fm kN/m | Am % | F at 0,5% kN/m | F at 1% kN/m | F at 1,5% kN/m | Strain at nom. load % | v-test %/min |
|---|---|---|---|---|---|---|---|---|
| x | 3243 | 70,50 | 2,31 | 23,25 | 35,89 | 48,43 | 1,17 | 19,50 |
| s | 76 | 1,65 | 0,16 | 2,14 | 2,04 | 2,11 | 0,09 | 1,21 |
| v | 2,34 | 2,34 | 7,11 | 9,21 | 5,68 | 4,35 | 7,45 | 6,19 |

**Note: Clamping area of grid protected with nonwoven**

## Wide-width tensile test
# DIN EN ISO 10319 (10.2008)

| | | | | |
|---|---|---|---|---|
| **Test Report No.** | **: 1.6/17810/0413.0.1-2012** | | **Material** | **: Fortrac R 50/50-40 B** |
| **Company** | **: HUESKER Synthetic GmbH** | | **Test direction** | **: MD** |
| **Operator** | **: de** | | **Test condition** | **: dry** |
| **Date** | **: 05.11.2012** | | | |

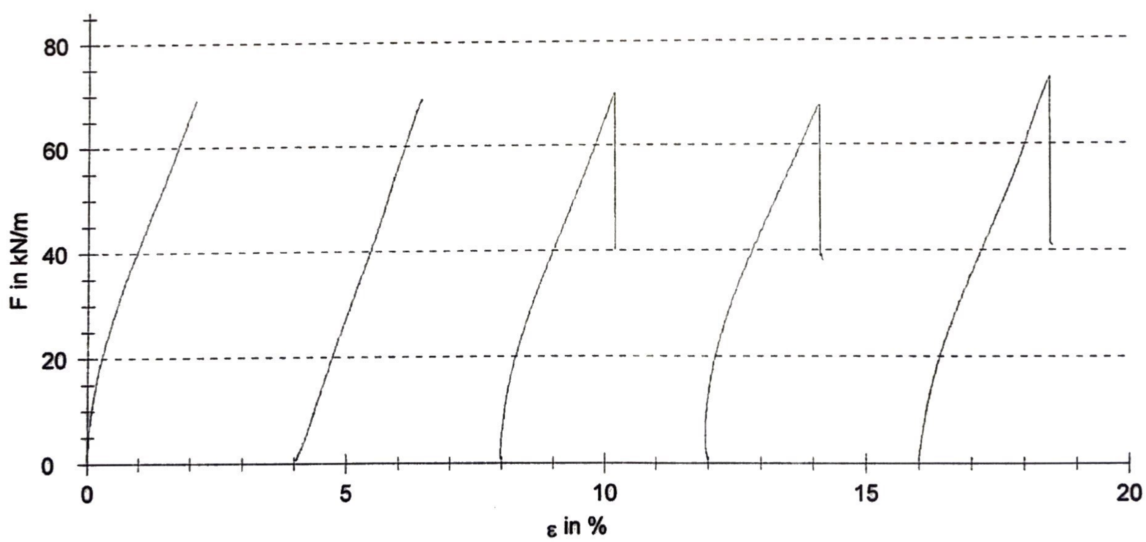
## Test parameters

| | | | |
|---|---|---|---|
| Climate | : 22 °C /42 % r. humidity | Specimen width b0 | : 46 mm |
| Machine | : Zwick Z250 | Teststrands | : 1 |
| Load cell | : 250 kN | Strands/ m | : 21,7 |
| Extensometer (path) | : Video | LE | : 100 mm |
| Specimen grips | : Demgen M250 | Pre-load | : 40 N |

## Results

| Nr | Fm<br>N | Fm<br>kN/m | Am<br>% | F at 0,5%<br>kN/m | F at 1%<br>kN/m | F at 1,5%<br>kN/m | Strain at nom. load<br>% | v-test<br>%/min |
|---|---|---|---|---|---|---|---|---|
| 1 | 3181 | 69,16 | 2,08 | 27,47 | 41,21 | 53,70 | 0,96 | 20,12 |
| 2 | 3181 | 69,16 | 2,44 | 13,43 | 27,86 | 41,45 | 1,45 | 22,14 |
| 3 | 3228 | 70,16 | 2,19 | 26,84 | 39,96 | 51,82 | 1,01 | 21,71 |
| 4 | 3102 | 67,45 | 2,12 | 31,64 | 43,65 | 54,14 | 0,84 | 22,04 |
| 5 | 3346 | 72,74 | 2,47 | 23,01 | 35,69 | 47,13 | 1,20 | 23,28 |

## Series graphics




## Statistics

| Serie<br>n = 5 | Fm<br>N | Fm<br>kN/m | Am<br>% | F at 0,5%<br>kN/m | F at 1%<br>kN/m | F at 1,5%<br>kN/m | Strain at nom. load<br>% | v-test<br>%/min |
|---|---|---|---|---|---|---|---|---|
| x̄ | 3208 | 69,73 | 2,26 | 24,48 | 37,67 | 49,65 | 1,09 | 21,86 |
| s | 89 | 1,94 | 0,18 | 6,90 | 6,20 | 5,36 | 0,24 | 1,14 |
| ν | 2,79 | 2,79 | 7,97 | 28,17 | 16,45 | 10,79 | 21,95 | 5,20 |

**Note: Clamping area of grid protected with PU-foam**

# Wide-width tensile test
# DIN EN ISO 10319 (10.2008)

Test Report No.: 1.6/17810/0413.0.1-2012
Company : HUESKER Synthetic GmbH
Operator : de
Date : 11.04.2012

Material : Fortrac R 50/50-40 B
Test direction : MD
Test condition : dry

## Test parameters

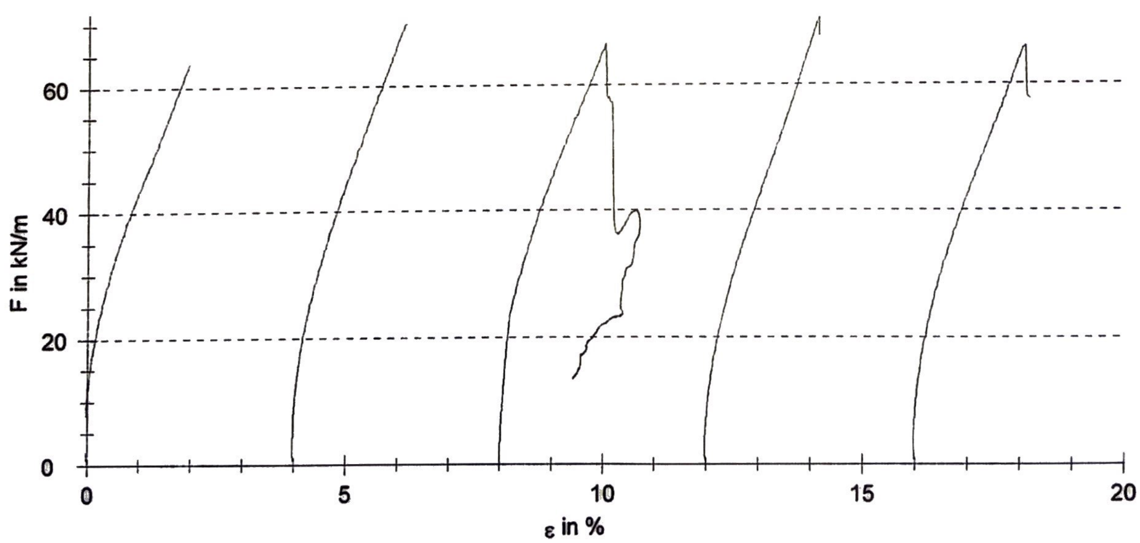
Climate : 22 °C /42 % r. humidity
Machine : Zwick Z250
Load cell : 250 kN
Extensometer (path): Video
Specimen grips : Demgen M250

Specimen width b0 : 46 mm
Teststrands : 1
Strands/ m : 21,7
LE : 100 mm
Pre-load : 30 N

## Results

| Nr | Fm N | Fm kN/m | Am % | F at 0,5% kN/m | F at 1% kN/m | F at 1,5% kN/m | Strain at nom. load % | v-test %/min |
|---|---|---|---|---|---|---|---|---|
| 1 | 2938 | 63,87 | 1,94 | 31,66 | 43,65 | 54,19 | 0,83 | 20,96 |
| 2 | 3221 | 70,02 | 2,14 | 31,48 | 44,67 | 56,06 | 0,81 | 22,80 |
| 3 | 3063 | 66,59 | 2,05 | 32,74 | 45,00 | 55,15 | 0,77 | 21,90 |
| 4 | 3252 | 70,69 | 2,18 | 29,15 | 41,62 | 53,10 | 0,94 | 21,71 |
| 5 | 3032 | 65,92 | 2,10 | 30,15 | 42,37 | 53,27 | 0,90 | 22,88 |

## Series graphics




## Statistics

| Serie n = 5 | Fm N | Fm kN/m | Am % | F at 0,5% kN/m | F at 1% kN/m | F at 1,5% kN/m | Strain at nom. load % | v-test %/min |
|---|---|---|---|---|---|---|---|---|
| x̄ | 3101 | 67,42 | 2,08 | 31,04 | 43,46 | 54,35 | 0,85 | 22,05 |
| s | 132 | 2,87 | 0,09 | 1,40 | 1,45 | 1,26 | 0,07 | 0,80 |
| ν | 4,26 | 4,26 | 4,48 | 4,51 | 3,34 | 2,32 | 7,71 | 3,64 |

**Note: Clamping area of grid protected with robust hardening epoxy resin**

## Wide-width tensile test
# DIN EN ISO 10319 (10.2008)

Test Report No.: 1.6/17810/0413.0.1-2012
Company : HUESKER Synthetic GmbH
Operator : de
Date : 05.04.2012

Material : Fortrac R 50/50-40 B
Test direction : MD
Test condition : dry

### Test parameters

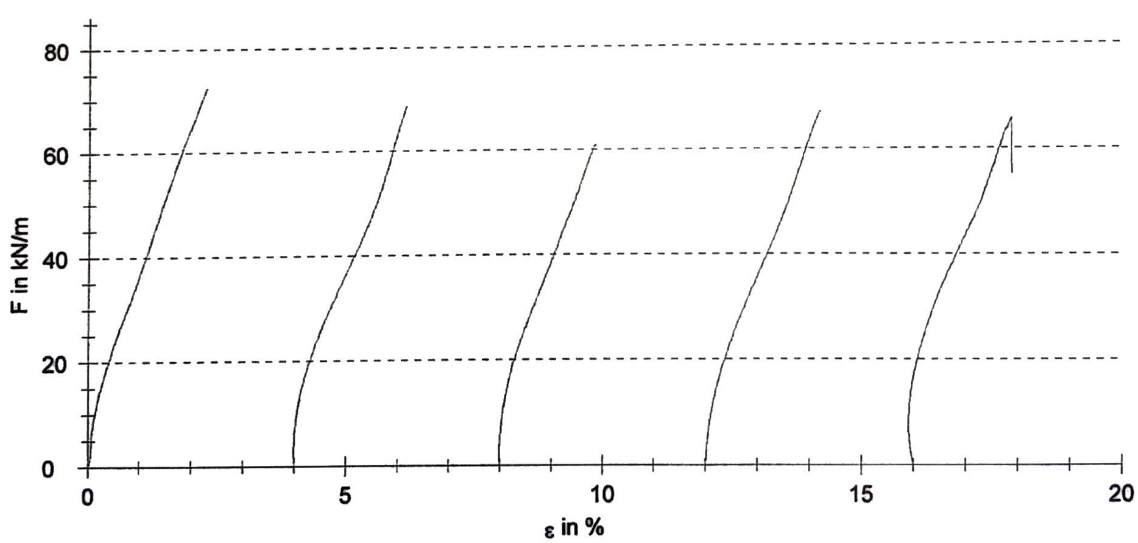
Climate : 22 °C /42 % r. humidity
Machine : Zwick Z250
Load cell : 250 kN
Extensometer (path): Video
Specimen grips : Demgen M250

Specimen width b0 : 46 mm
Teststrands : 1
Strands/ m : 21,7
LE : 100 mm
Pre-load : 30 N

### Results

| Nr | Fm N | Fm kN/m | Am % | F at 0,5% kN/m | F at 1% kN/m | F at 1,5% kN/m | Strain at nom. load % | v-test %/min |
|---|---|---|---|---|---|---|---|---|
| 1 | 3337 | 72,55 | 2,27 | 22,94 | 36,68 | 51,58 | 1,12 | 13,85 |
| 2 | 3159 | 68,68 | 2,15 | 25,88 | 36,84 | 48,10 | 1,15 | 18,40 |
| 3 | 2804 | 60,96 | 1,86 | 26,07 | 38,65 | 51,61 | 1,06 | 17,05 |
| 4 | 3091 | 67,21 | 2,21 | 23,42 | 35,50 | 47,35 | 1,20 | 19,02 |
| 5 | 3026 | 65,77 | 1,87 | 32,83 | 43,64 | 55,72 | 0,83 | 15,44 |

### Series graphics




### Statistics

| Serie n = 5 | Fm N | Fm kN/m | Am % | F at 0,5% kN/m | F at 1% kN/m | F at 1,5% kN/m | Strain at nom. load % | v-test %/min |
|---|---|---|---|---|---|---|---|---|
| x̄ | 3084 | 67,03 | 2,07 | 26,23 | 38,26 | 50,87 | 1,07 | 16,75 |
| s | 195 | 4,23 | 0,19 | 3,95 | 3,21 | 3,34 | 0,14 | 2,13 |
| ν | 6,31 | 6,31 | 9,21 | 15,07 | 8,39 | 6,57 | 13,47 | 12,70 |

**Note: Clamping area of grid protected with soft hardening epoxy resin**

# Determination of the creep rupture behaviour
# DIN EN ISO 13431 (11.1999)

Date: 11.04.2012

**Test Report No.** : **1.6/17810/0413.0.1-2012**
**Company** : **HUESKER Synthetic GmbH**
**Material** : **Fortrac R 50/50-40 B**
**Operator** : **cs/de**

## Test parameters

| | |
|---|---|
| Climate | : 23 °C / 45 % rel. humidity |
| Specimen width | : 1 strand |
| Test direction | : MD (machine direction) |
| Test apparatus (Short time < 100h) | : Zwick Z250 / Zwick Z050 / Instron 5567 |
| Test apparatus (Long time > 100h) | : vertical steel frame - load is applied by lever arm |
| Clamping system | : hydr. clamps / roller clamps |
| Method for Tensile strength | : DIN EN ISO 10319 (10.2008) |
| Ultimate tensile strength UTS | : 70,5 kN/m (3243 N at specimen width of 1 strand) |
| Strain at max. load | : 2,3 % |

## Results

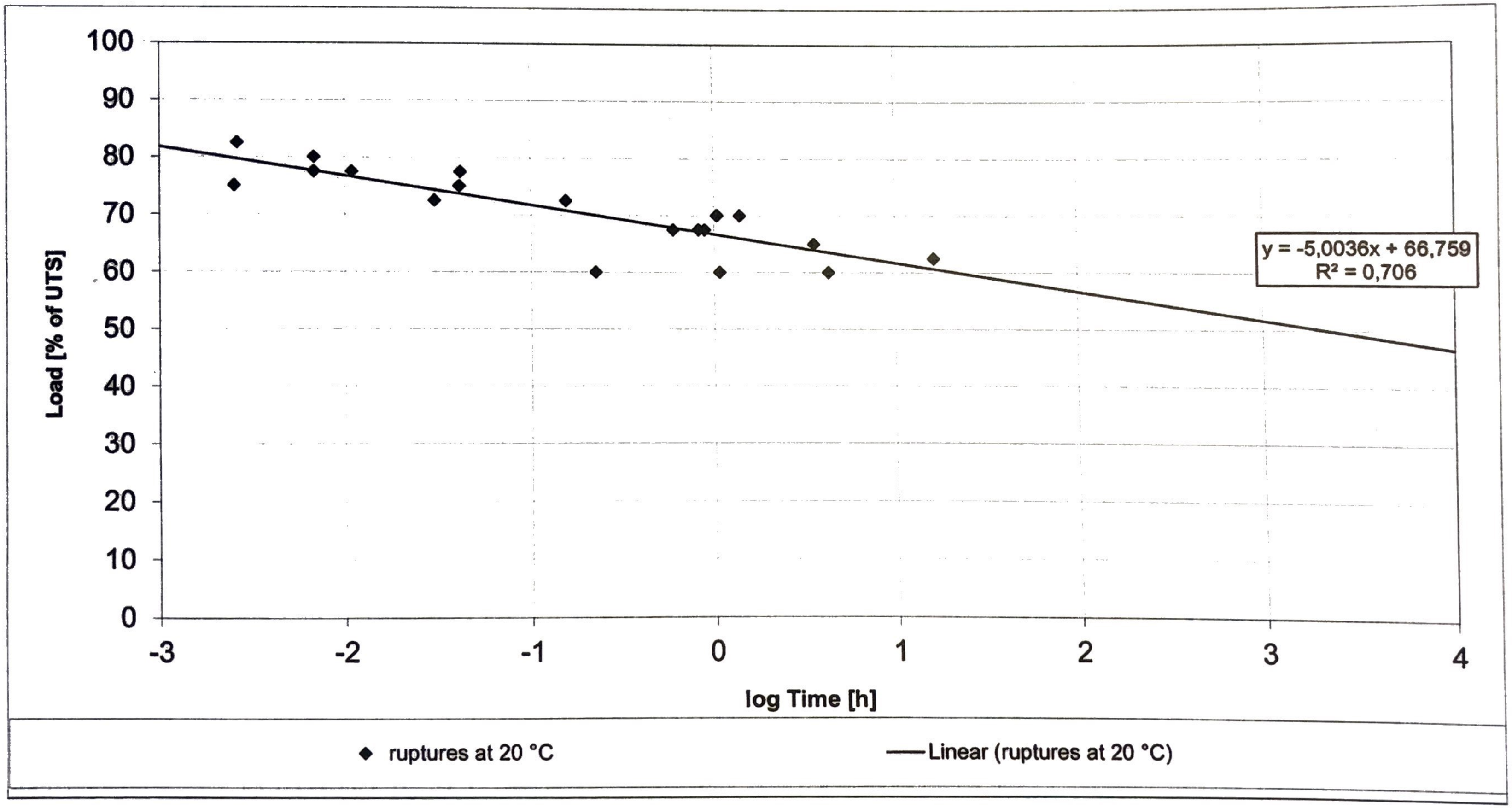
| Load [% of UTS] | Load [N] | Time [h] | log Time [h] |
|---|---|---|---|
| 82,5 | 2675 | 0,003 | -2,579 |
| 80,0 | 2594 | 0,007 | -2,165 |
| 77,5 | 2513 | 0,007 | -2,165 |
| 77,5 | 2513 | 0,011 | -1,961 |
| 77,5 | 2513 | 0,042 | -1,376 |
| 75,0 | 2432 | 0,041 | -1,384 |
| 75,0 | 2432 | 0,003 | -2,596 |
| 72,5 | 2351 | 0,030 | -1,517 |
| 72,5 | 2351 | 0,156 | -0,808 |
| 70,0 | 2270 | 1,046 | 0,020 |
| 70,0 | 2270 | 1,037 | 0,016 |
| 70,0 | 2270 | 1,389 | 0,143 |
| 67,5 | 2189 | 0,889 | -0,051 |
| 67,5 | 2189 | 0,596 | -0,225 |
| 67,5 | 2189 | 0,822 | -0,085 |
| 65,0 | 2108 | 3,569 | 0,553 |
| 62,5 | 2027 | 16,40 | 1,215 |
| 60,0 | 1946 | 0,224 | -0,649 |
| 60,0 | 1946 | 4,287 | 0,632 |
| 60,0 | 1946 | 1,074 | 0,031 |

Note : Clamping area of grid protected with nonwoven

## Determination of the creep rupture behaviour
## DIN EN ISO 13431 (11.1999)

Date: 11.04.2012

| | | |
|---|---|---|
| **Test Report No.** | : | **1.6/17810/0413.0.1-2012** |
| **Company** | : | **HUESKER Synthetic GmbH** |
| **Material** | : | **Fortrac R 50/50-40 B** |
| **Test direction** | : | **MD (machine direction)** |
| **Raw material** | : | **Basalt** |
| **Operator** | : | **cs/de** |



## Determination of the creep rupture behaviour
## DIN EN ISO 13431 (11.1999)

Date: 15.11.2012

| | |
|---|---|
| **Test Report No.** | **: 1.6/17810/0413.0.1-2012** |
| **Company** | **: HUESKER Synthetic GmbH** |
| **Material** | **: Fortrac R 50/50-40 B** |
| **Operator** | **: cs/de** |

### Test parameters

| | |
|---|---|
| Climate | : 23 °C / 45 % rel. humidity |
| Specimen width | : 1 strand |
| Test direction | : MD (machine direction) |
| Test apparatus (Short time < 100h) | : Zwick Z250 / Zwick Z050 / Instron 5567 |
| Test apparatus (Long time > 100h) | : vertical steel frame - load is applied by lever arm |
| Clamping system | : hydr. clamps / roller clamps |
| Method for Tensile strength | : DIN EN ISO 10319 (10.2008) |
| Ultimate tensile strength UTS | : 69,7 kN/m (3208 N at specimen width of 1 strand) |
| Strain at max. load | : 2,3 % |

### Results

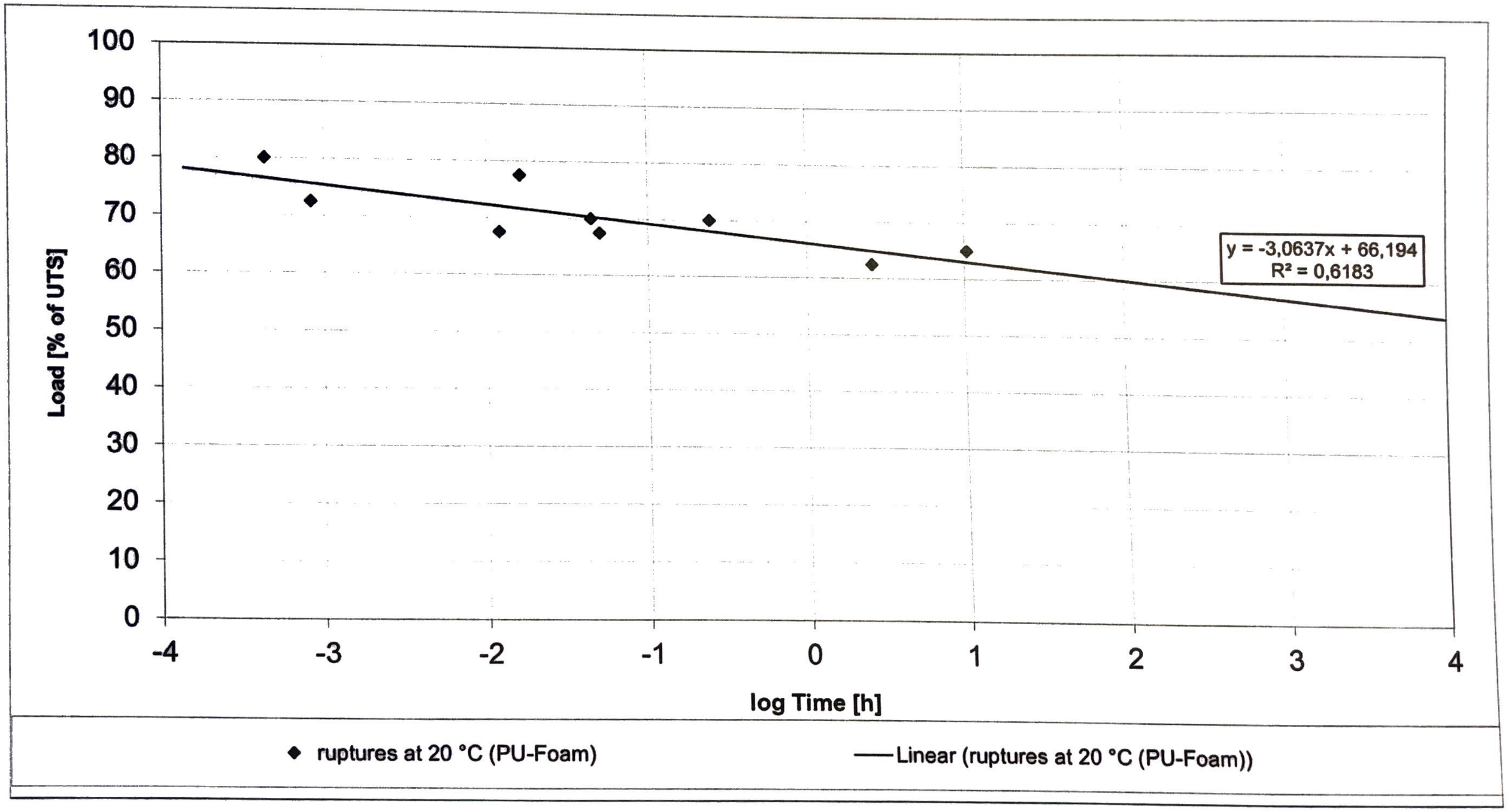
| Load [% of UTS] | Load [N] | Time [h] | log Time [h] |
|---|---|---|---|
| 80,0 | 2566 | 0,0004 | -3,363 |
| 77,5 | 2486 | 0,016 | -1,792 |
| 72,5 | 2326 | 0,001 | -3,079 |
| 70,0 | 2246 | 0,244 | -0,612 |
| 70,0 | 2246 | 0,044 | -1,356 |
| 67,5 | 2165 | 0,050 | -1,303 |
| 67,5 | 2165 | 0,012 | -1,923 |
| 65,0 | 2085 | 10,43 | 1,018 |
| 62,5 | 2005 | 2,596 | 0,414 |

Note : Clamping area of grid protected by PU-foam

**Determination of the creep rupture behaviour**
**DIN EN ISO 13431 (11.1999)**

Date: 15.11.2012

| | | |
|---|---|---|
| **Test Report No.** | : | **1.6/17810/0413.0.1-2012** |
| **Company** | : | **HUESKER Synthetic GmbH** |
| **Material** | : | **Fortrac R 50/50-40 B** |
| **Test direction** | : | **MD (machine direction)** |
| **Raw material** | : | **Basalt** |
| **Operator** | : | **cs/de** |



# Determination of the creep rupture behaviour
# DIN EN ISO 13431 (11.1999)

Date: 15.11.2012

**Test Report No.** : 1.6/17810/0413.0.1-2012
**Company** : HUESKER Synthetic GmbH
**Material** : Fortrac R 50/50-40 B
**Operator** : cs/de

## Test parameters

| | |
|---|---|
| Climate | : 23 °C / 45 % rel. humidity |
| Specimen width | : 1 strand |
| Test direction | : MD (machine direction) |
| Test apparatus (Short time < 100h) | : Zwick Z250 / Zwick Z050 / Instron 5567 |
| Test apparatus (Long time > 100h) | : vertical steel frame - load is applied by lever arm |
| Clamping system | : hydr. clamps / roller clamps |
| Method for Tensile strength | : DIN EN ISO 10319 (10.2008) |
| Ultimate tensile strength UTS | : 67,4 kN/m (3101 N at specimen width of 1 strand) |
| Strain at max. load | : 2,1 % |

## Results

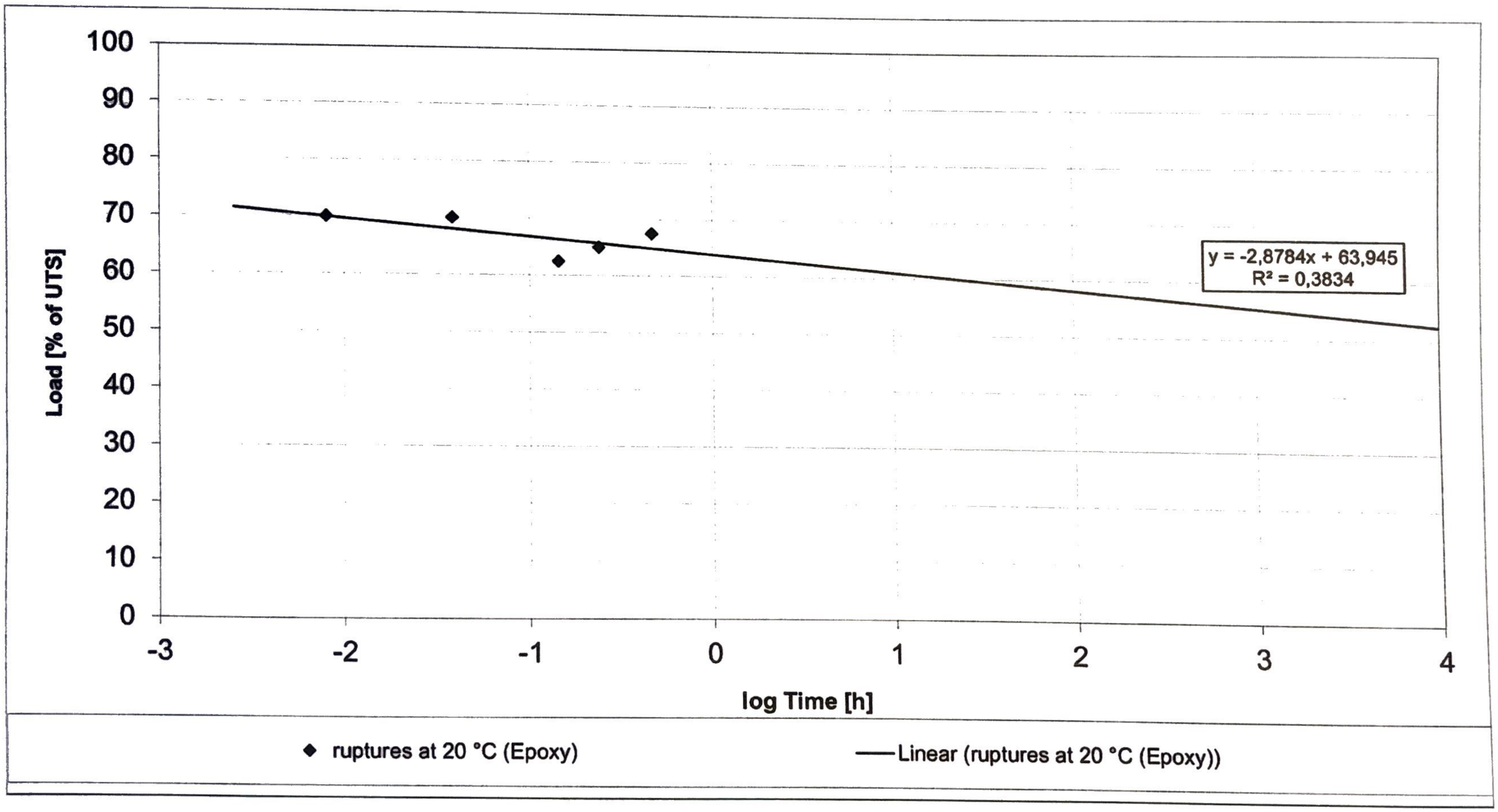
| Load [% of UTS] | Load [N] | Time [h] | log Time [h] |
|---|---|---|---|
| 70,00 | 2171 | 0,008 | -2,095 |
| 70,00 | 2171 | 0,038 | -1,415 |
| 67,50 | 2093 | 0,466 | -0,331 |
| 65,00 | 2016 | 0,238 | -0,623 |
| 62,50 | 1938 | 0,144 | -0,842 |

Note : Clamping area of grid protected with robust hardening epoxy resin

**Determination of the creep rupture behaviour**
**DIN EN ISO 13431 (11.1999)**

Date: 15.11.2012

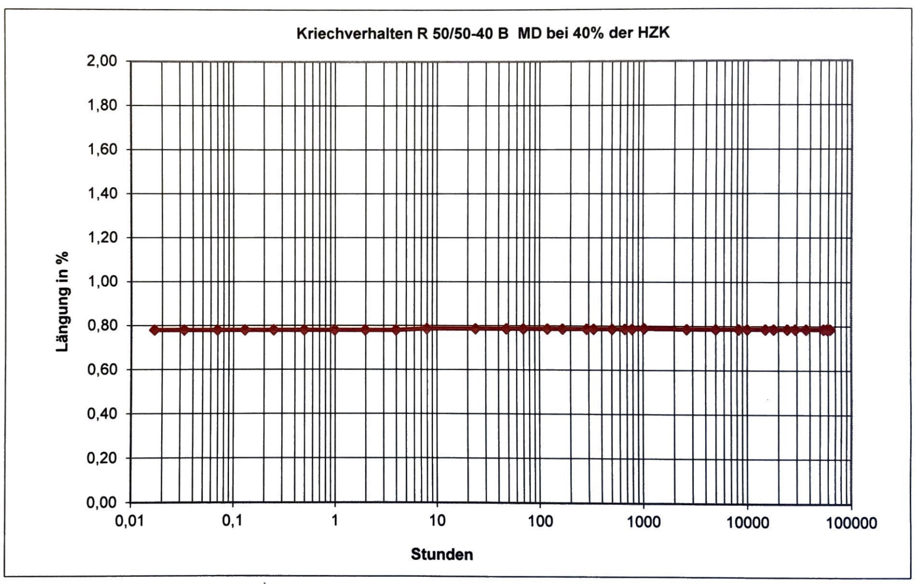
| | | |
|---|---|---|
| **Test Report No.** | : | **1.6/17810/0413.0.1-2012** |
| **Company** | : | **HUESKER Synthetic GmbH** |
| **Material** | : | **Fortrac R 50/50-40 B** |
| **Test direction** | : | **MD (machine direction)** |
| **Raw material** | : | **Basalt** |
| **Operator** | : | **cs/de** |



## R 50/50-40 B

**Kriechverhalten MD bei 40%**
Ausgangslänge in mm 143,5

| Zeit in h | Änderung in % | Änderung in mm |
|---|---|---|
| 0,017 | 0,78 | 1,12 |
| 0,033 | 0,78 | 1,12 |
| 0,07 | 0,78 | 1,12 |
| 0,13 | 0,78 | 1,12 |
| 0,25 | 0,78 | 1,12 |
| 0,5 | 0,78 | 1,12 |
| 1 | 0,78 | 1,12 |
| 2 | 0,78 | 1,12 |
| 4 | 0,78 | 1,12 |
| 8 | 0,79 | 1,13 |
| 24 | 0,79 | 1,13 |
| 48 | 0,79 | 1,13 |
| 70 | 0,79 | 1,13 |
| 120 | 0,79 | 1,13 |
| 168 | 0,79 | 1,13 |
| 288 | 0,79 | 1,13 |
| 336 | 0,79 | 1,13 |
| 508 | 0,79 | 1,13 |
| 672 | 0,79 | 1,13 |
| 792 | 0,79 | 1,13 |
| 1032 | 0,79 | 1,13 |
| 2640 | 0,79 | 1,13 |
| 5014 | 0,79 | 1,13 |
| 8354 | 0,79 | 1,13 |
| 10108 | 0,79 | 1,13 |
| 15072 | 0,79 | 1,13 |
| 18121 | 0,79 | 1,13 |
| 24528 | 0,79 | 1,13 |
| 29205 | 0,79 | 1,13 |
| 37077 | 0,79 | 1,13 |
| 54685 | 0,79 | 1,13 |
| 58880 | 0,79 | 1,13 |




29.04.2022

# Appendix G

# Project thesis

Henrik Faye

# Geotextiles based on basalt for erosion control and reinforcement purposes

A literature study of mechanical and hydraulic properties for synthetic and natural based geotextiles and their environmental impact

Trondheim, December 2021

PROJECT THESIS: TBA4510

Main supervisor: Professor Rao Martand Singh

Co-supervisor: Arnstein Watn

Department of Civil and Environmental Engineering

Norwegian University of Science and Technology (NTNU)

NTNU – Trondheim
Norwegian University of
Science and Technology

## Preface

This thesis is the project thesis for TBA 4510 Geotechnics, specialization project. It is written as a preliminary study for the master's thesis. The master's thesis is planned to be carried out during spring 2022 at the Department for Civil and Environmental Engineering at NTNU.

The original plan for my project- and master thesis was to investigate how microbiologically induced calcium carbonate precipitation could be used to stabilize poor soils. With strict restrictions regarding the handling of the bacteria, it was not an opportunity to continue with this work.

Prof. Singh and Watn proposed to study geotextiles based on basalt fibers. This is a new technology in the geotechnical industry. A project in Germany has been mentioned where it has been discussed to use basalt based geotextiles for erosion control and reinforcement purposes. If so, the product needs to be tested and designs have to be made.

I would like to thank Prof. Rao Martand Singh and Arnstein Watn for supervising through the semester. In addition, I would like to thank Lars Chr. Fredenlund in CoBuilder for valuable insight in how standardization processes work and the built environment in general.

Trondheim, 2021-12-19

Henrik Faye

## Abstract

Geotextiles are used in various applications within geotechnical engineering. It may provide cheaper and easier constructions than conventional methods where, for example, concrete is used. It is used for reinforcement purposes in walls, slopes, embankments and more. The composite material then consisting of earth and the reinforcement material will have both compression and tensile capacity whereas soil alone don't have tensile capacity. The magnitude of the capacity is depending on the materials used. Synthetics are mostly used. The strength properties of different synthetics vary a lot, so the right material has to be chosen for the right task. Organic materials as jute and coir has been used for decades, but might have insufficient strength properties. Inorganic materials as basalt is an emerging material. It has the required strength properties in addition to environmental benefits compared to synthetics due to its' natural origin.

The natural origin means that the material can also be well suited for erosion purposes. Here, the task of the geotextile will be to prevent material from being washed out of the earth skeleton due to water or wind. As the material breaks down it will chip up. The chips will be transported with water in the water cycle and will become part of natural ecosystems. When synthetic materials are broken down, microplastics will end up in ecosystems, which is not desirable. Organic materials will decompose quickly and will not be harmful to nature. Basalt will not degrade in the same way as natural materials, but since it is a natural material, it will not damage ecosystems in the same way as plastic.

These properties form a good basis for the development of geotextiles based on basalt. In several projects, the combination of reinforcement and erosion control will be relevant and basalt may in these cases be a suitable material. As there is not done much work on this, further research is required to understand how the material works in conjunction with soil in the built environment.

## Sammendrag

Geotekstiler brukes i ulike sammenhenger innenfor geoteknikk. Det kan gi billigere og enklere konstruksjoner enn konvensjonelle metoder hvor det for eksempel brukes betong. Det brukes til forsterkningsformål i vegger, skråninger, voller med mer. Komposittmaterialet som da er bestående av jord og armeringsmaterialet vil ha både kompresjons- og strekkkapasitet, mens jord alene ikke har strekkapasitet. Hvor stor kapasiteten er avhenger av materialene som brukes. Syntetiske stoffer brukes mest. Styrkeparametrene til forskjellige syntetiske materialer varierer mye, så riktig materiale må velges til riktig bruk. Organiske materialer som jute og kokosfiber har vært brukt i flere tiår, men kan ha utilstrekkelige styrkeegenskaper til forsterkningsformål. Uorganiske materialer som basalt er et materiale som kan være interessant å bruke innenfor geoteknikk. Basalt har de nødvendige styrkeegenskapene som kreves for forsterkning, i tillegg til miljømessige fordeler sammenlignet med syntetiske stoffer på grunn av sin naturlige opprinnelse.

Den naturlige opprinnelsen gjør at materialet også kan egne seg godt til erosjonsformål. Her vil geotekstilens oppgave være å hindre at materiale vaskes ut av jordskjelettet på grunn av vann eller vind. Etterhvert som materialet brytes ned vil det flises opp. Flisene vil bli fraktet med vann i kretsløpet og vil bli en del av naturlige økosystemer. Når syntetiske materialer brytes ned vil mikroplast havne i økosystemene, som ikke er ønskelig. Organiske materialer vil brytes ned relativt raskt og vil ikke være skadelig for naturen. Basalt vil ikke brytes ned på samme måte som naturlige materialer, men ettersom det er et naturlig materiale vil det ikke skade økosystemene på samme måte som plast.

Disse egenskapene danner et godt grunnlag for utviklingen av geotekstiler basert på basalt. I flere prosjekter vil kombinasjonen av forsterkning og erosjonskontroll være relevant og basalt vil i disse tilfellene kunne være et egnet materiale. Ettersom det er lite brukt til dette kreves det videre forskning for å forstå hvordan materialet fungerer i samvirke med jord.

# Contents

# List of Figures

# List of Tables

# Chapter 1

# Introduction

The use of geotextiles is a well-known and well-used technical solution in geotechnical design. According to R. M. Koerner (2016), the use of stabilization attempts of peat bogs date back to 3000 B.C. Back then timber was the primary material in use. As more and more surface area of the earth is used by the built environment, the need for methods to build on poor soils has increased. The first use of fabric to fill this purpose was attempted in 1926 by the South Carolina Highway Department in a road project (R. M. Koerner 2016). The project showed that the fabric, made from natural fibers, reduced cracking and raveling before it deteriorated. Since then the use of geotextiles has increased. The technique has shown to be ideal in various projects due to a relative low cost compared to alternative methods and easy installation.

## 1.1 Background

Most geotextiles in use today are based on synthetic materials, often petroleum-based. The production of these materials have a negative impact on our environment. Microplastics is yet another problem. Recent studies show that plastic materials will leave fragments over time. These fragments takes long time to degrade and will disrupt the ecosystems where they are deposited (Cózar et al. 2014; Hale et al. 2020; Petersen & Hubbart 2021; Horton & Dixon 2018). This is especially the case in or near river systems and in the sea, where the fragments are transported and deposited by the water. How they are transported is hard to analyze. Natural materials without same problems regarding degradation exists. Unfortunately, their service life is often significantly shorter, and most of them do not have the properties that modern engineering needs.

This have aroused interest for new materials.

Especially for erosion control purposes, which is often combined with reinforcement purposes, a new material will be of interest. The product type most suitable for this use is geotextiles.

Basalt fibers for use in geotextiles has been proposed. As far as the author is concerned, there is not much literature available on this. It has been used in other industries, where the strength and fire properties of basalt is of importance. How the material is produced and some literature on the material properties can be found.

## 1.2 Term

There is not really a good existing collective term for geotextiles, geogrids, geonets, geomembranes etc. that is not restricted to be based on synthetic material. Geosynthetics is a collective term for these products, but it does not include natural materials. There is no such term for both synthetic and natural based products. Most materials in use for this are synthetic based. Most natural based products are geotextiles, but we will most likely see other types of products in the future when hopefully natural materials have a bigger presence.

## 1.3 Limitations

As there is a lot of different applications for geotextiles not all of them can be covered in depth. The focus will be on erosion control and reinforcement of walls and slopes. There are numbers of different ways to design solutions for problems related to this. Different designs and calculations methods will hardly be touched.

To use basalt fibers in a composite material may be very interesting. As it is a material with properties alike glass- and carbon fiber it would most likely perform well in a composite. There has been done a lot of research on composites as fiber-reinforced polymers. As there is so many various ways to make a composite, depending on what materials used, the content of each material and how they are aligned etc. the properties of polymers and relevant natural materials will rather be covered. There has also been done a lot of work on synthetic geotextiles. Only a fraction of this work will be included.

The basalt industry is not as big in western countries as it is in countries as Russia and China.

There may exist publications from these countries on the material written in their respective languages. If so, they are not included as their language is not understood.

The thesis will focus on geotextiles, not geogrids, geocells, geomembranes or other product types. Even though some of these product types could be used for erosion control and especially reinforcement the focus will be on geotextiles.

# Chapter 2

# Geotextiles

The word geotextile is quite self-explanatory. It is composed of two words; geo and textile. Geo means earth and a textile is, well, a textile. The geotextile is to be used in conjunction with earth.

## 2.1 Manufacturing methods

As the name geotextile reveals, the material manufacturing process of the material is based on the same processes as traditional textiles. According to Bérubé & Saunier (2016) there are four main geotextile types today:

- non-woven
- woven
- knitted
- composite

**Non-woven**

For given applications, the most common type is the non-woven. Another name for this is felts. It is made from fibers that can be assembled in different manners. Needle-punching is the most common one (Bérubé & Saunier 2016). Usually the process is divided into short stable fiber process and continuous filament process as shown in Figure 2.1 (R. M. Koerner 2012).

For the short stable fiber process, the fibers are chosen to match the wanted properties of the textile. Different polymers or natural materials as well as various dimensions can be chosen.

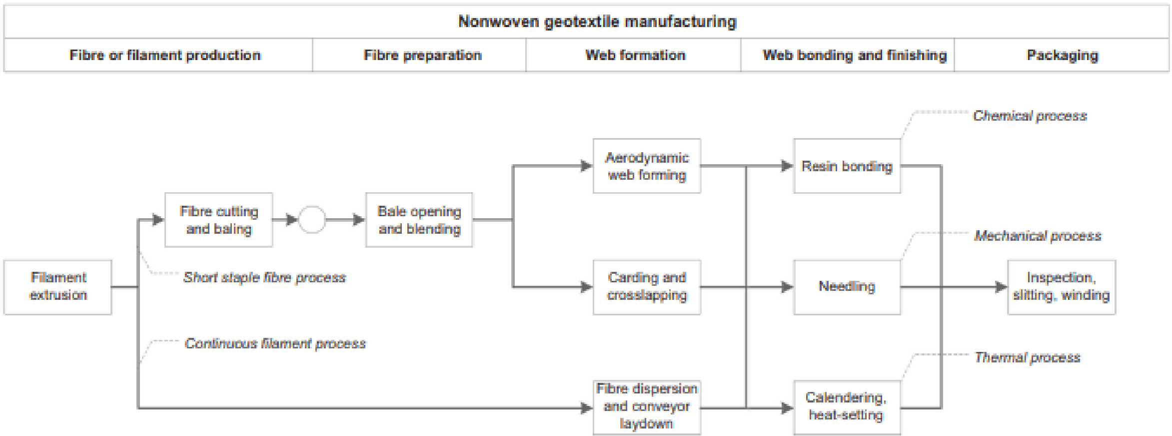



Figure 2.1: Manufacturing process of non-woven geotextiles (R. M. Koerner 2012)

They are mixed into a homogeneous blend. Thereafter the fibers can be aligned in a certain pattern or they can be randomly distributed. The thickness is chosen. The most common step in the process is then needle-punching. Other less common processes for short stable fibers are heat bonding or chemical bonding of the textile. However, these processes are often used in the finalization of the product. In the needling process, the textile is punched with needles moving up and down. This movement creates a random structure to the fibers. The penetration depth, speed, number of needles, and the size and shape of the needle can be adjusted to get the wanted properties of the product. When the needling process is done, the geotextile may be exposed to chemical or thermal processes to give it its' final properties.

The continuous filament process is a little different. Pellets with the chosen material are fed into an extruder, where the material is melted and sent through a spinneret with holes of specific dimension and form. The material is cooled and stretched before it is randomly distributed to an apron and a web is formed. Thereafter it is most common to bond the web in a heat process, especially for synthetic materials, but needling can also be used. In the heat process, the material fuses together in the parts where it is overlapping (Bérubé & Saunier 2016).

#### Woven

Yarns, filaments or slit film tapes are used for woven geotextiles. They are weaved together in a traditional manner. Longitudinal threads are interwined with transversal threads. Some of the threads are lowered and others are raised to form the wanted pattern. The pattern of the fabric and how tightly it is woven will influence the pore size of the product. Typical patterns are plain weave and twill weave, shown in Figure 2.2.

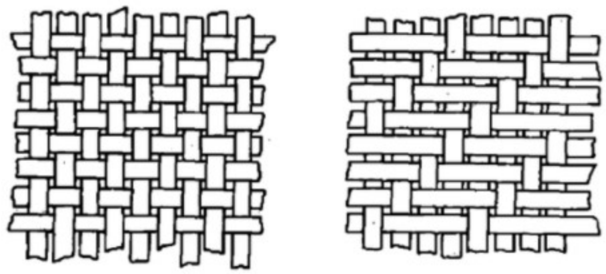


Figure 2.2: Plain weave to the left and twill weave to the right (Bloom 2015)

Figure 2.3 shows the manufacturing process.

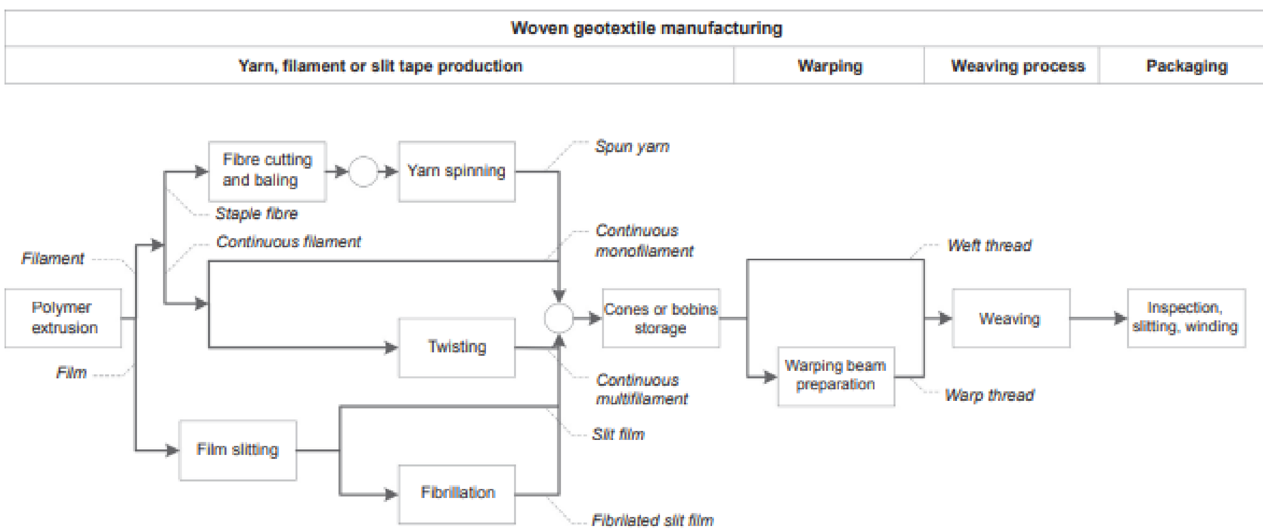



Figure 2.3: Manufacturing process of woven geotextiles (R. M. Koerner 2012)

Whether the product is non-woven or woven may be confusing at first look. The non-woven can be identified by its fuzzy look. Whether the non-woven or woven is best depends on the type of project it is intended to be used in. Generally, non-wovens are used for separation and filtration functions. They often have higher permittivity. Wovens tend to have higher strength properties and are not elongated to the same extent as non-wovens. This makes them more popular in reinforcement applications.

**Knitted**

Knitting is another possible way to produce a geotextile. In the knitting process, continuous yarns are intertwined to form repeated loops. By linking these loops a web is formed. The density of the material can be varied. The most common knitting processes are weft knitting and warp knitting.

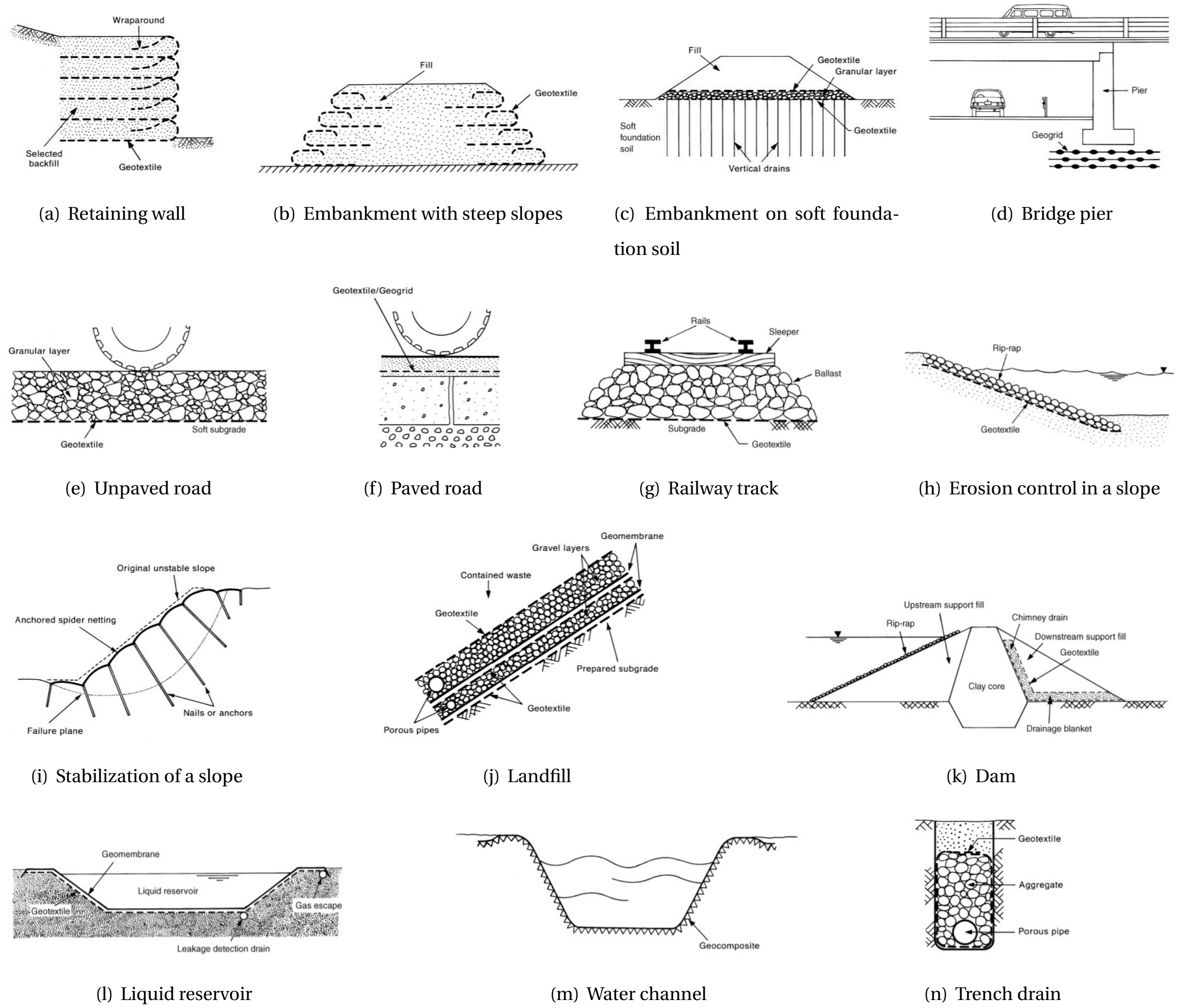
**Composite**

It is common, at least in recent years, to use composite materials to get the specific properties that are required. Often these composites consists of a polymer with elements of other materials such as natural fibers (H. Wu et al. 2020). Chemical, mechanical and/or heat processes can be used in the manufacturing process.

## 2.2 Functions and applications

Although the focus in this thesis is on erosion control and reinforcement, geotextiles are used in numerous projects with different purposes. Their major functions can be categorized as separation, reinforcement, filtration, drainage and moisture barrier (R. M. Koerner 2012). In the European and Norwegian standard NS-EN 13251 by Standard Norge (2016), Table 1 divides the functions of a geotextile and geotextile-related products into separation, reinforcement and filtration. NorGeoSpec has the same division as the European standards (NorGeoSpec 2012).

A selection of applications is shown in Figure 2.4.




(a) Retaining wall (b) Embankment with steep slopes (c) Embankment on soft foundation soil (d) Bridge pier

(e) Unpaved road (f) Paved road (g) Railway track (h) Erosion control in a slope

(i) Stabilization of a slope (j) Landfill (k) Dam

(l) Liquid reservoir (m) Water channel (n) Trench drain

Figure 2.4: Typical applications for geosyntetics and geosynthetic-related materials (Shukla & Yin 1987)

The most important properties for each function are summed up in Table 2.1

Table 2.1: Properties and functions of geotextiles

| | Mechanical properties | | | | | Hydraulic properties | | |
|---|---|---|---|---|---|---|---|---|
| | **Puncture** | **Tensile strength** | **Compression** | **Tearing** | **Elongation** | **Permeability** | **Flow capacity** | **Pore openings** |
| **Separation** | x | | | x | | x | | x |
| **Reinforcement** | | x | | x | x | | | |
| **Filtration** | | | x | | | x | | x |

For Nordic countries the book “Nordisk håndbok armert jord og fyllinger” issued by the Nordic goetechnical associations gives guidance on how to design with geotextiles. The International Geosynthetic Society (IGS) and its’ norwegian division IGS Norge are up to date on what is happening in the industry.

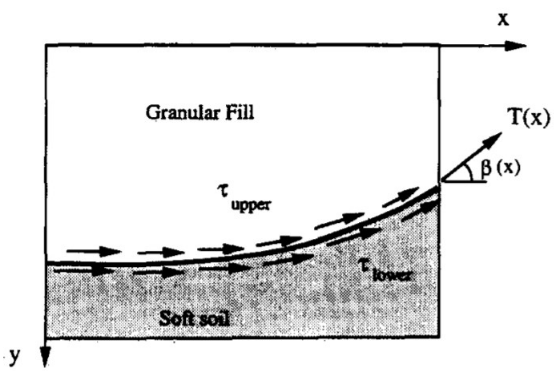
### 2.2.1 Separation

When used for separation, the purpose of the geotextile is to separate different fractions with different properties. For instance, it is often not wanted to mix coarse materials as stones with fine grained materials as silt, as the drainage properties of the stone and the strength of the stone will worsen.

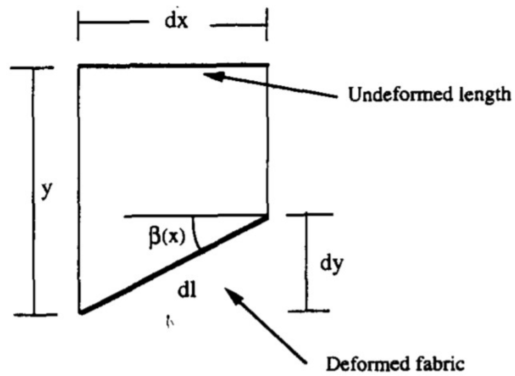
### 2.2.2 Reinforcement

As soil have good compression properties but bad tensile properties, geotextiles are a good match with its' tension properties to form a system with both compression and tension capabilities. The need for such properties may be in constructions as slopes or embankments for stabilization purposes. In the 60s the concept of reinforced soil, or terre armée as it was called in french, was developed by the french architect and engineer Henri Vidal (1969). The essence of the technique was to make a material with cohesion based on non-cohesive particles. Earth materials of all particle sizes, as silt, sand, gravel, stones and all sizes of rock, combined with reinforcement, defined as all linear components which can withstand major tensile stresses, would fulfill this. Originally the reinforcement was thought of as elongated elements with one dimension clearly greater than the others, more like strips. With the development of this technique, the reinforcement does not necessarily have to be strips. It can be of various forms and may stretch out in more than one directions. The term geotextile-reinforced soil (GRS) is widely used today.

The way forces are distributed in a GRS may be described with the use of the following figures and equations:




(a) Forces acting between the geotextile and soil




(b) Forces acting on an infinite element

Figure 2.5: Principal sketch of forces between soils and geotextile (Espinoza 1994)

If no slippage is assumed, the geotextile will support some of the applied load and decrease the applied vertical stress on the underlaying soil (Espinoza). From Figure 2.5 the following relationship can be established:

$$tan\beta(x) = \frac{dy}{dx} \tag{2.1}$$

$$T_h = T(x)cos\beta(x) \tag{2.2}$$

$$T_v = T(x)sin\beta(x) \tag{2.3}$$

where $x$ is the horizontal coordinate from the lowest point in the deformed geotextile, $y(x)$ is the vertical displacement of the geotextile from its undeformed geometry, $\beta(x)$ is the angle between the deformed geotextile and the horizontal line, and $T(x)$ is the tensile force of the geotextile with $T_h$ and $T_v$ as the horizontal and vertical components.

To obtain equilibrium for the infinite piece in Figure 2.5(b), some assumptions have to made. A relationship between $\tau_{upper}$ and $\tau_{lower}$ needs to be established. Whether the deformed geotextile has a circular or parabolic shape, if the strain in the geotextile is constant or variable, and the boundary conditions for the problem needs to be defined. A differential equation can be made based upon these assumptions. With the specific material parameters, the improvement made by the geotextile may be evaluated.

For numerical calculations based on the final element method, softwares as PLAXIS may be used to determine how geotextiles act in interaction with soils (Bentley Group 2021). In PLAXIS, geogrids is the structural element used to model geotextiles. The elements have axial stiffness but no bending stiffness. Different material models may be chosen to simulate the material in a realistic manner. The available options are elastic, elastoplastic, elastoplastic ($N-\epsilon$) and visco-elastic (time-dependent). In the more advanced models the maximum tension force is specified. The time dependency may also be modelled. The material can be modelled to act isotropically or anisotropically. Thermal properties as specific heat capasity, thermal conductivity, density, thermal expansion coefficient and area (for thermal expansion) may be specified. Another important aspect of modelling in PLAXIS is the interface option. The interaction between soil and material is specified through $R_{inter}$ or $R_{inter,residual}$. Permeability is modelled as well.

#### Reinforced slopes and walls

Normally, a slope will be able to stand by itself if the inclination is less than the friction angle of the material, when cohesion is not taken into account. The friction angle of a material may vary a lot. Often it is in the area between 17 to 45 degrees for the most common inorganic soils where it may be appropriate to use reinforcement techniques (Faggruppe for geoteknikk NTNU 2018). In many cases it may be desirable to have steeper slopes than the friction angle allows. Conventionally this has been solved with the use of masonry or concrete structures. Following the development of Vidal (1969), the slopes could be built steeper without the use of masonry or concrete.

Vidals original system was built up by an earth material, the reinforcement strips and a skin. The skin would be the face of the structure with the main purpose of retaining earth particles not in contact with the reinforcement. It should exhibit adequate local resistance and overall flexibility, provide drainage, be simple to put in place and not corrode. The optimal shape for the skin was a semi-elliptical cylindrical form. A sketch of this system is shown in Figure 2.6.

Let us assume that the principle stresses at all points are parallel and perpendicular to the general line of the surface of the skin. The ratio between the stresses is denoted $\frac{\sigma_1}{\sigma_3} = i$. The membrane theory then states that the stable shape for the skin is a semi-ellipse with ratio $\sqrt{i}$ between the axes (Vidal 1969).

The failure mechanisms of a reinforced soil wall is shown in Figure 2.7. Rogbeck et al. (2006)

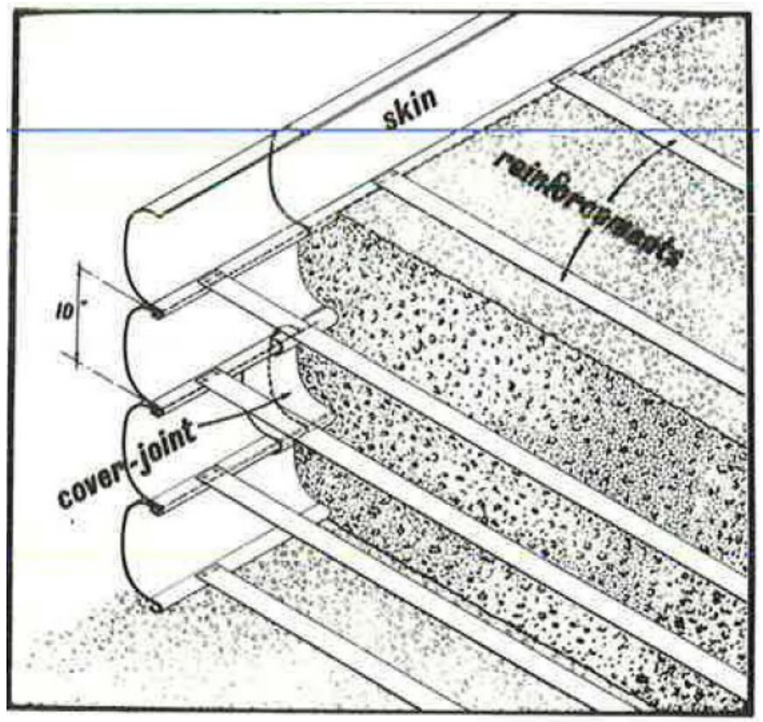



Figure 2.6: Vidals system with reinforced earth (Vidal 1969)

includes some more mechanisms, but the ones shown are the basic ones.

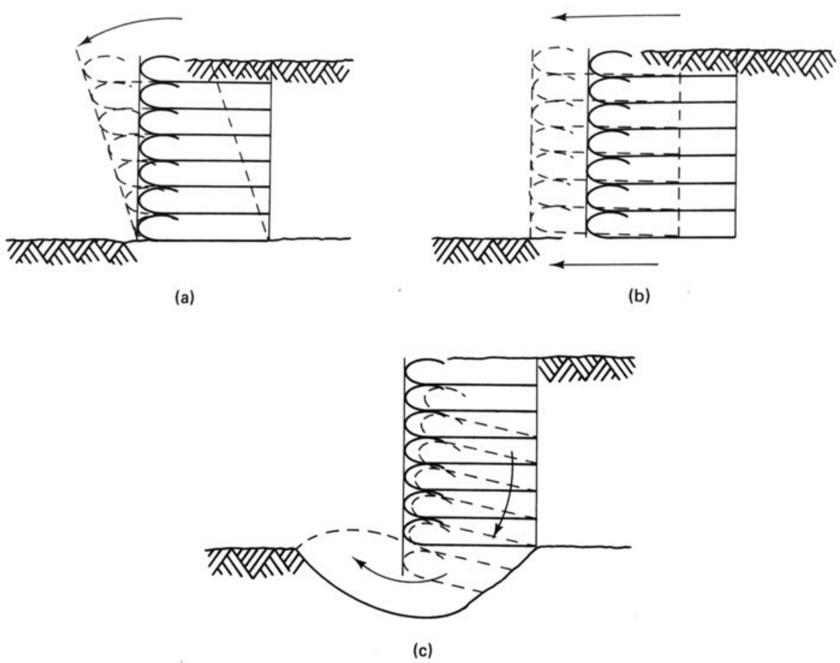



Figure 2.7: Failure mechanisms of a reinforced soil wall (Rimoldi 2016)

As reinforced earth walls gained popularity with the years, new designs were developed.

In 1993, Clayborn and Wu released an article where six design methods using geosynthetic-reinforced soils were reviewed (Claybourn & J. T. H. Wu 1993). The authors state that these methods were the most frequently used methods in North American engineering practice. Basic sketches of six designs for a 3,6 m high wall reinforced with geotextiles are given in Figure 2.8.

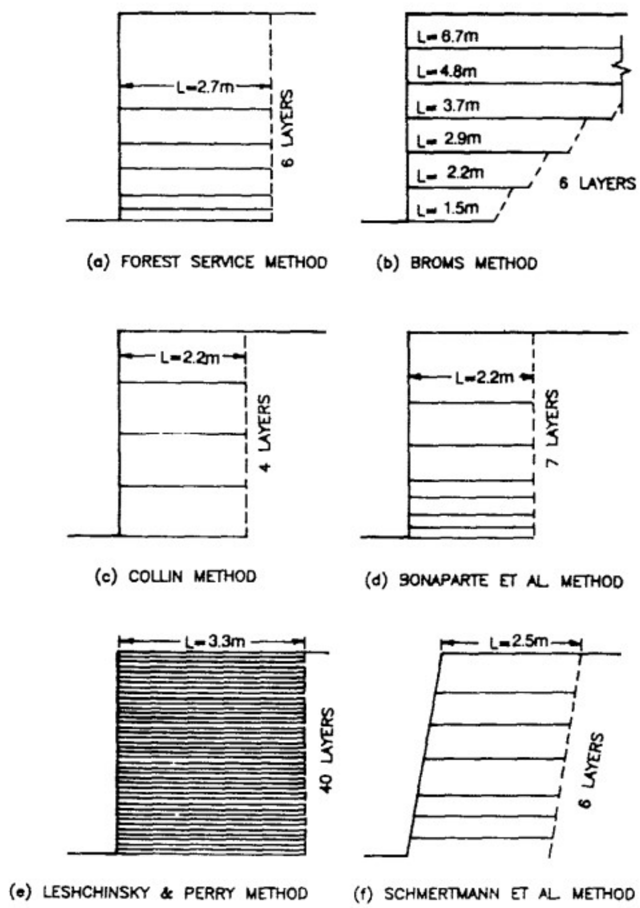



Figure 2.8: Comparison of the six given designs (Claybourn & J. T. H. Wu 1993)

Calculation methods for the Forest Service method (Steward et al. 1977), Broms method (Broms 1978), Collin method (Collin 1986), Bonaparte et al. method (Bonaparte et al. 1987), Leshchinsky Perry method (Leshchinsky & Perry 1987) and Schmertmann et al. method (Schmertmann et al. 1987) can be found in the respective references. New calculation methods have been developed since. Rimoldi presents calculation methods and procedures in his work (Rimoldi 2016), Rogbeck et al. (2006) presents calculation methods and so on.

**Reinforced embankments**

Reflection cracking in asphalt? Reduce settlement Prevent local failure mechanisms

If reinforcement is not used in an embankment, horizontal deformations and mobilization of shear stress at the bottom of the filling caused by the earth pressure may occur. This may cause spread breakage. With the use of reinforcement, tensile stresses and shear stresses in the lower part of the filling will be reduced as they are transferred to the textile. This will increase the bearing capacity as the critical shear surface will go deeper and becomes longer (Bergado et al. 2002). The reinforcement will reduce the degree of mobilization of the subsoil. The roughness at foundation level is decreased and will increase the load-bearing capacity factor $N_c$ (Vegvesen V220). The situation both without and with reinforcement is shown in Figure 2.9.


(a) Embankment without reinforcement

(b) Embankment with reinforcement

Figure 2.9: Failure modes of embankments without and with reinforcement (Vegvesen, V221)

Various calculations methods exists; they may be given as standards or guidelines from country to country. Manufacturers may also have guidelines for calculations.

### 2.2.3 Filtration

For filtration purposes, geotextiles may be used behind retaining walls, around underdrains, in erosion control structures and as silt fences. The geotextile should fulfill two purposes; to allow water to pass through so that there is no buildup of excess pore pressure, that may be caused by clogging, and to retain the finest particles of the soil so that they do not get washed out.

For reinforcement control, the main goal is to avoid small particles to be dislodged from the soil caused by water or wind. It may happen due to waves, overland water flow, rain or winds. The functions of the geotextile is then to provide for containment, dynamic filtration, screening, surface stabilization and vegetative reinforcement (C. J. Sprague & J. E. Sprague 2016). The textile is either actively controlling the soil dislodgement or it is intercepting the dislodged soil. This is called erosion control and sediment control respectively.

The intended service life may be short term or medium to long term. If the service life is short term, the geotextile's function is normally to keep the earth in place until the vegetation does this task properly. In medium to long term service life, the construction may be in an area with a great erosion potential where the natural vegetation is insufficient for this purpose.

The excess pore pressure that may build up if the fabric is too tight or blocked by particles will cause the effective stresses in the soil to reduce. This will again lower the factor of safety for the structure. The permeability of the textile should be adequate to avoid this. The cross-plane permeability may be determined from the following equations based on Darcy's formula with constant head (Koerner):

$$\psi = \frac{k_n}{t} \tag{2.4}$$

where $\psi$ = permittivity, $k_n$ = permeability coefficient normal to the fabric, and $t$ = thickness of the fabric.

$$\begin{aligned} q &= kiA \\ &= k_n \frac{\Delta h}{t} A \end{aligned} \tag{2.5}$$

$$\frac{k_n}{t} = \psi = \frac{q}{\Delta h A} \tag{2.6}$$

where $q$ = flow rate, $\Delta h$ = head lost, and $A$ = area of fabric.

It may also be determined with a falling head. Darcy's formula is then integrated over the head before and after q is measured (R. Koerner 2016):

$$\frac{k_n}{t} = \psi = 2.3 \frac{a}{A \Delta t} log_{10} \frac{h_0}{h_f} \tag{2.7}$$

where $a$ = area of water supply standpipe, $\Delta t$ = time change between $h_0$ and $h_f$, $h_0$ = head at beginning of test, and $h_f$ = head at end of test.

As mentioned, the opening size should not be too big as it will allow the finer fractions to be washed out from the soil skeleton, called soil piping. If soil piping occurs, the finer grains will be washed out, which will make soil voids grow, which will lead to a higher water velocity, which again will transport even more of the finer grains until the soil structure begins to collapse. Various methods to determine the correct opening size of the geotextile exists.

In addition, clogging should be avoided. Empirically, one must avoid that these three conditions occurs to avoid clogging (R. Koerner 2016):

- Cohesionless sands and silts
- Gap-graded particle size distributions
- High hydraulic gradients

## 2.3 Properties and test methods

Different design properties of the geotextile needs to be determined. R. M. Koerner (2012) divides the properties into physical, mechanical, hydraulic, endurance and environmental properties.

In Europe, Comité Européen de Normalisation (CEN) is the body that develops and maintains European standards, verifications and test methods. Standard Norge is the Norwegian member of CEN. When new standards and test methods are developed or renewed, a technical committee is responsible. For geotextiles and geotextile-related products, technical committee 189 is responsible. All relevant standards for Norway on geotextiles can be found in *NS ICS 59.080.70 Standardsamling for geotekstiler.*

All the properties of products used in a construction that are important for the construction to meet the basic requirements of the technical regulations must be documented. Certain notified bodies may issue documentation of properties. 24 bodies exists in Norway. SINTEF is the certification body for NorGeoSpec 2012. NorGeoSpec 2012 is a system for certification, specification and control testing of geosynthetics, and sets requirements for the products depending on the intended use. NorGeoSpec is a cooperation between the road authorities in Norway, Finland, Sweden and Estonia. Whether the intended use for the product is separation and filtration or reinforcement decides what tests it has to be put through. The relevant test standards for Product Specification is given in Table 2.2 whereas Table 2.3 and Table 2.4 are relevant for Product Certification.

Table 2.2: Required values for product specification (NorGeoSpec 2012)

| | **Function: separation and filtration** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Characteristic** | **Testing standard** | **Unit** | **Maximum tolerance [1)]** | **Required[2)] values corresponding to 95% confidence limit** | | | | |
| | | | | **Product Specification profiles** | | | | |
| | | | | **1** | **2** | **3** | **4** | **5** |
| Min tensile strength | EN ISO 10319 | kN/m | -10% | 6 | 10 | 15 | 20 | 26 |
| max. load | EN ISO 10319 | % | -20% | 15 | 20 | 25 | 30 | 35 |
| Max cone drop diameter | EN ISO 13433 | mm | +25% | 44 | 38 | 28 | 22 | 13 |
| Min energy index | | kN/m | | 1.2 | 2.1 | 3.2 | 4.5 | 6.5 |
| Min velocity index | EN ISO 11058 | $10^{-3}$ m/s | -30% | 3 | 3 | 3 | 3 | 3 |
| Max characteristic opening size, $O_{90}$ | EN ISO 12956 | mm | ±30% | 0.2 | 0.2 | 0.2 | 0.15 | 0.15 |
| Max tolerance for mass per unit area | EN ISO 9864 | g/m² | ±10% | | | | | |
| Max tolerance for static puncture strength | EN ISO 12236 | kN | -10% | | | | | |

1) The tolerance shall be stated by the manufacturer; this table gives the maximum allowable tolerance.

2) The tolerances are not to be added to the required values. The nominal values ± the tolerance shall fulfil the requirement.

Table 2.3: Certified values with tolerance (in % of values) depending on the function fulfilled by the product for Product Certificate testing (NorGeoSpec 2012)

| **Characteristic** | **Standard** | **Unit** | **Function** | | |
|---|---|---|---|---|---|
| | | | Filtration | Separation | Reinforcement |
| **Product identification** | | | | | |
| Mass per unit area[1)] | EN ISO 9864 | g/m² | ± 10 % | ± 10 % | ± 10 % |
| Tensile elements | Annex F | | n.r. | n.r. | Manufacturer's data |
| Dimensions | Annex F [2)] | mm | n.r. | n.r. | ± 15 % |
| **Mechanical tests** | | | | | |
| Max tensile strength | EN ISO 10319[3)] | kN/m | -10 % | -10 % | n.r |
| Tensile strain at max tensile load | EN ISO 10319 | % | -20 % | -20 % | n.r |
| Nominal tensile strength | EN ISO 10319 | kN/m | n.r | n.r | -5 % |
| Tensile strain at nominal strength | EN ISO 10319[3)] | % | n.r. | n.r. | ± 20 % |
| Tensile stiffness at 2, 5, 10% tensile strain | EN ISO 10319 | kN/m | n.r. | n.r. | -20 % |
| Static puncture test | EN ISO 12236 | kN | -10 % | -10 % | -10%[4)] |
| Dynamic perforation resistance | EN ISO 13433 | mm | +25 % | +25 % | +25%[4)] |
| **Hydraulic tests** | | | | | |
| Permeability normal to the plane without load | EN ISO 11058 | mm/s | -30 % | -30 % | -30 %[4)] |
| Characteristic opening size | EN ISO 12956 | μm | ±30 % | ±30 % | ±30 %[4)] |

[1)] We regard the plus/minus NGS-tolerance on the mass per unit area as an indication of the process stability. Process stability means that the process delivers constant, predictable results.

[2)] Applicable only for geogrids (definition acc. EN ISO 10318).

[3)] MD and CMD direction. For uniaxial products, test only the direction of load uptake

[4)] Voluntary

n.r. = not required

Table 2.4: Determination of reduction factors for Product Certificate testing (NorGeoSpec 2012)

| Characteristic | Standard | Requirements |
|---|---|---|
| Resistance to weathering | EN 12224 | $RF_W$ |
| Chemical resistance [1] | EN 12447<br>EN ISO 13438<br>EN 14030 | $RF_{CH}$ |
| Tensile creep rupture | EN ISO 13431<br>ASTM D 6992 | $RF_{CR}$ |
| Damage during installation | Annex G | $RF_{ID}$ |
| Direct shear test [2] | EN ISO 12957-1 | Manufacturer declaration |

$RF_W$ = reduction factor for weathering
$RF_{CH}$ = reduction factor for environmental effects
$RF_{CR}$ = reduction factor for creep-rupture
$RF_{ID}$ = reduction factor for installation damage
[1] Depending on raw material
[2] Voluntary

### 2.3.1 Physical

Regarding physical properties, the specific gravity, mass per unit area, thermal properties, and geometric measures as dimensions, thickness and pore opening size are the most important ones. The pore opening size is determined by *ISO 12956 Geotextiles and geotextile-related products — Determination of the characteristic opening size.*

### 2.3.2 Mechanical

For some non-wovens, the compressibility of the material is of importance as it will affect the hydraulic properties. The more it is compressed under load, the lower its' transmissivity. Figure 2.10 shows how the thickness varies with pressure for non-woven and woven products (Shukla & Yin 1987). For woven, non-woven heat-set or heavily calendered fabrics, the compressibility is not of importance.

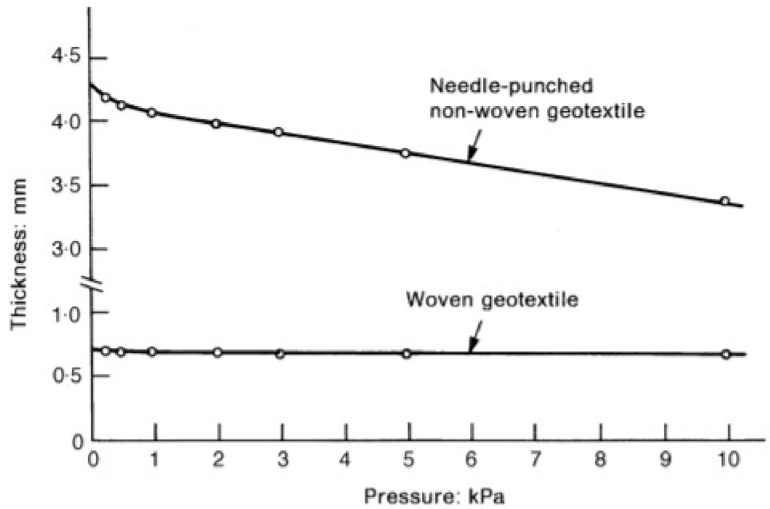



Figure 2.10: Variation of thickness with pressure (Shukla & Yin 1987)

For all geotextiles, the tensile strength is one of the most important parameters. For reinforcement use, it is obvious that this parameter is important. The tensile strength may be important as a secondary function in other applications. When the tensile strength of a product is tested, the principle is to fix both ends of the fabric and elongate it in tension until failure occurs, while the strain in the material is measured. Generally, wovens will have less strain than non-wovens and reach a higher tensile stress. Test apparatus with a non-woven and a woven product is shown in Figure 2.11.

(a) Non-woven geotextile

(b) Woven geotextile

Figure 2.11: Wide-width tensile test on geotextiles using hydraulic clamps (Zanzinger 2016)

For the tensile strength, elongation at maximum load and stiffnesses at different strains, *ISO 10319 Geosynthetics — Wide-width tensile test* describes test methods and calculations. The specimen is tested to rupture. It is held across its entire width by a set of clamps and exposed to a constant displacement speed. The strain rate should be $(20 \pm 5)\%$ per minute in the gauge length of the specimen generally. With the method presented in the Eurocode, the width is greater than the length of the specimen. This is to avoid contraction (necking) under loading in the gauge length area, which is typical for geotextiles. It will resemble a relationship closer to the one in the field.

The European standards also tests for static puncture resistance in *ISO 12236 Geosynthetics — Static puncture test (CBR test)*. A specimen is held in place by two metal rings. A plunger with given geometry is pushed through the specimen at a constant rate of $(50 \pm 5)$ mm/min. The force and displacement is logged and used to determine the results.

In the cone drop test, specified by *ISO 13433 Geosynthetics — Dynamic perforation test (cone drop test)*, a specimen is placed between the clamp rings in the apparatus free of slack. The cone is then released from a height of $(500 \pm 2)$ mm to the center of the specimen. A measuring cone is immediately placed into the hole, and the diameter of the hole is thereafter measured.

### 2.3.3 Hydraulic

*ISO 11058 Geotextiles and geotextile-related products — Determination of water permeability characteristics normal to the plane, without load* describes the test methods for determination of water permeability characteristics for geotextiles and geotextile-related products. Two test methods are presented; one with constant head and one with falling head.

#### Constant head

In the test with constant head, a head loss of $(70 \pm 5)$ mm is required. The head should be held constant throughout the test. The water run-through should be at least 10 $cm^3$ and last at least 30 seconds. The test is done with different head losses starting with the highest velocity for 70 mm head then 0.8, 0.6, 0.4 and 0.2 times the highest head. The flow velocity is calculated as:

$$v_{20} = \frac{V R_T}{A t} \tag{2.8}$$

where $V$ = the water volume measured $[m^3]$, $R_T$ = the correction factor for water temperature $T$, in degrees Celsius, to a water temperature of $20°C$, $A$ = the exposed specimen area $[m^2]$, and $t$ = the time measured to achieve the volume V $[s]$.

The temperature correction is found as:

$$v_{20} = v_T R_T \tag{2.9}$$

where $v_{20}[\frac{mm}{s}] = q[\frac{L}{m^2 s}]$.

The head loss $H$ is plotted against the velocity $v_{20}$ for each head loss and should be presented in one graph. The flow velocity for a head loss of 50 mm should be found.

#### Falling head

A unidirectional flow of water is applied normal to the plane of the geotextile under a falling head. The test continues until the head loss and velocity reaches zero. This is done for five test specimens. The flow velocity for a chosen water-level interval is calculated as:

$$v_{20} = q = \frac{\Delta h}{t} R_T \tag{2.10}$$

where $\Delta h$ = the difference between the upper water level, $h_u$, and the lower water level, $h_l$, in meters for a time interval $t$, $t$ = the time interval between $h_u$ and $h_l$ in seconds, and $R_T$ = the correction factor for water temperature $T$. The head loss is calculated as:

$$H = h_u + h_l - 2h_0 \tag{2.11}$$

where $h_0$ = the height of the water level at $v$ = 0 m/s, $h_u$ = the upper water level of the head range, and $h_l$ = the lower water level of the head range.

In the same way as for a constant head, the head loss $H$ is plotted against the velocity $v_{20}$ for the specimens tested. The best-fit curve through the origin for each specimen is found. The flow velocity for a head loss of 50 mm should be found.

### 2.3.4 Endurance and environmental

The question of endurance for geotextiles is central. Materials prone to the ravages of time will degrade. It is of interest to know what causes this degradation, how sensitive the construction is to this and how the materials may be tested with respect to endurance properties. Reduction factors are introduced in the design of structures to handle this.

It is known that most materials will creep. Creep is the permanent deformation that occurs with time when the load and temperature is constant (Penny & Marriott 2012). Various creep tests exists. In Europe, *ISO 13431 Geotextiles and geotextile-related products — Determination of tensile creep and creep rupture behaviour* is the standard for determination of tensile creep. The principle is quite simple; a test specimen is loaded with a constant static force under constant temperature and humidity. The load is maintained for 1000 h. This is done for four load levels. For each of them, the gauge length should be measured at time intervals from start until 1000 h is reached or should be measured continuously. The creep strain versus log time for each specimen, for each creep load, is plotted and the creep coefficient may be determined.

R. M. Koerner (2012) and the American industry talks about abrasion whereas Europe talks about durability. In Europe and Norway, weathering is handled in *EN 12224* or *NS 12224 Geotekstiler og geotekstilrelaterte produkter - Bestemmelse av motstand mot forvitring.*

Resistance to damage during installation caused by granular material is tested in *ISO 10722 Geosynthetics — Index test procedure for the evaluation of mechanical damage under repeated loading — Damage caused by granular material (laboratory test method).* The specimen is placed between two layers of granular material. It is subjected to a dynamic loading for a period. The specimen is then put to mechanical tests. The results for the damaged specimen is compared to the results for an undamaged reference specimen. NorGeoSpec also test according to Annex G in NorGeoSpec (2012).

Chemical resistance is treated in *NS 12447 Geotekstiler og geotekstilrelaterte produkter — Utsilingsprøving for bestemmelse av motstand mot hydrolyse i vann* and *ISO 13438 Geosynthetics — Screening test method for determining the resistance of geotextiles and geotextile-related products to oxidation.*

## 2.4 Green geotextiles

Jeon (2016) defines green geotextiles as follows: "Green geosynthetics are made of eco-environmental biodegradable polymeric resins or natural materials that maintain their needed performance such as durability, design strength, hydraulic property, etc., during the service period. Then, after the service period they degrade leaving no harmful effects within the soil structure."

It is natural to think that the decomposition mechanisms are most important to control for long term purposes where these may affect the strength and therefore the safety of the construction. For short term purposes, it is important in the way that they should not pollute the environment.

The definition of Jeon (2016) includes polymeric resins as well as natural materials. The focus in the definition is on the degradation process. In order to be acknowledged as a green geotextile the production process also needs to be accounted for.

The production process for polymeric materials is obviously not sustainable. Hydrocarbons from the petroleum industry form the basis of production. The estimated service life of the product may to some degree compensate for this as it is relatively long. In this way, the products don't need to be changed as often as products with a shorter estimated service life which affects the demand and production.

Natural based geotextiles naturally have other degradation mechanisms than synthetic. Generally they are less harmful when deteriorated. Jute for example is be biodegradable. This will be the case for most plant and animal based natural materials. Mineral materials doesn't have the same mechanisms. The production processes may be energy consuming and polluting. This must be included in the overall accounts.

# Chapter 3

# Geotextiles based on synthetic material

According to Elwood (2004), synthetic geotextiles account for more than 90 % of the market. This is probably due to their low production cost and high potential for customization. From 1960 and further on, the use of synthetics have really increased, phasing out natural materials as grass, flax, bamboo and jute (Hsuan et al. 2008).

## 3.1 Materials

Polyester (PET), polypropylene (PP), polyethylene (PE) and polyamide (PA) are the most used materials according to Shukla & Yin (1987). R. M. Koerner (2012) says the same with the exception of PA. Table 3.1 shows the estimated percentages of the different materials in the market.

Table 3.1: Estimated percent in use for PP, PE and PET (Elwood 2004)

| **Geosynthetic** | **Types of polymer** | **Estimated percentage in use** |
|---|---|---|
| | Polypropylene (PP) | 90 % |
| Geotextiles | Polyethylene (PE) | 5 % |
| | Polyester (PET) | 5 % |

The properties of different plastics may vary a lot. This is due to factors as polymer density, melt flow rate, draw ratio, polymer additives etc. (Shukla & Yin 1987). The desired properties are possible to obtain by variations of these factors.

## 3.2 Typical material parameters for geosyntetics

General material characteristics for typical polymers used in geotextiles are given in Table 3.2. They are given as low, medium or high as the values will vary a lot with different additives.

Table 3.2: Overview of properties for different plastic materials (Shukla & Yin 1987)

| Properties | | Polymers | | | |
|---|---|---|---|---|---|
| | | PP | PET | PA | PE |
| Strength | | Low | High | Medium | Low |
| Modulus | | Low | High | Medium | Low |
| Strain at failure | | High | Medium | Medium | High |
| Creep | | High | Low | Medium | High |
| Unit weight | | Low | High | Medium | Low |
| Cost | | Low | High | Medium | Low |
| Resistance to ultraviolet light | Stabilized | High | High | Medium | High |
| | Unstabilized | Medium | High | Medium | Low |
| Resistance to alkalis | | High | Low | High | High |
| Resistance to fungus, vermin, insects | | Medium | Medium | Medium | High |
| Resistance to fuel | | Low | Medium | Medium | Low |
| Resistance to detergents | | High | High | High | High |

Availability and low costs is probably the reason why PP is most popular, as shown in Table 3.1. In addition, the material has excellent chemical and pH range resistance. It does not have great UV-resistance originally, but with the use of additives and stabilizers it may get it. However it is not suited for reinforcement purposes, as it has fairly poor creep characteristics. For separation and filtration purposes it is a cost-effective alternative.

Polyester is more suited for reinforcement purposes. The material has better creep characteristics and higher tensile strength. Regarding degradation mechanisms, it is resistant to UV and chemical degradation, with the exception of very alkaline environments.

Polyethylene comes in different molecular weights resulting in different densities. They are named high-density PE (HDPE), medium-density PE (MDPE), linear low-density PE (LLDPE) and low-density polymer (LDPE). HDPE is the most common in geotextile making.

The thickness varies between 0.25 mm to 7.5 mm for most geotextiles.

The tensile strength varies from material to material and for different production methods. Generally, woven filaments have higher tensile strength. Figure 3.1 shows the tensile strength for woven and non-woven PP geotextiles.

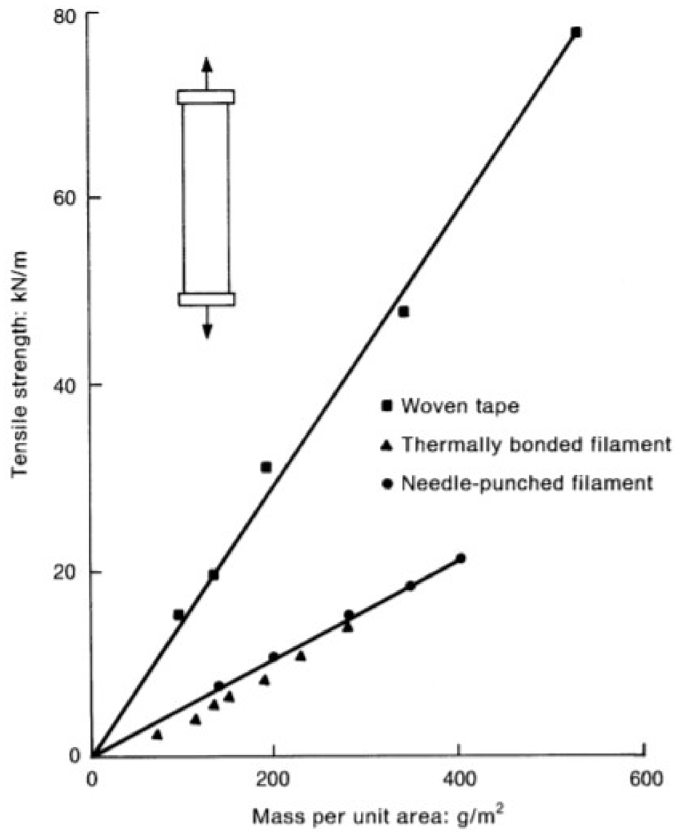



Figure 3.1: Variation of tensile strength with mass per unit area for PP geotextiles (Ingold & Miller 1988)

Recommended applications for different types of polymers are listed in Table 3.3.

Table 3.3: Recommended applications for different types of polymers

| **Geosynthetic** | **Type of polymer** | **Function** | | |
|---|---|---|---|---|
| | | **Separation** | **Reinforcement** | **Filtration** |
| Geotextile | Polyester (PET) | (Recommended) | Recommended | (Recommended) |
| | Polypropylene (PP) | Recommended | Not recommended | Recommended |
| | Polyethylene (PE) | Recommended | Not recommended | Recommended |
| | Polyamid (PA) | Recommended | Not recommended | Recommended |

## 3.3 Advantages and challenges with geosynthetics

As synthetic materials are most popular it clearly have some advantages. One of the biggest is the price compared to what it delivers. The petroleum industry is immense. With the growth of the industry over the years the prices on petroleum products have decreased. At the same time, the r&d on geosynthetics has made it possible to improve mechanical properties due to new production methods, assembly methods, design methods and other technological advances.

Synthetic products have environmental issues. There is a desire to scale down the petroleum industry. And with this the production of polymers as well. The world is slowly changing from energy and products based on oil and gas towards other renewable energy sources and sustainable products.

Even though polymer-based solutions for geotechnical engineering may have some environmental constraints in that way, the alternative solutions may not be better. For instance, when geotextiles are used for reinforcement purposes the alternative could have been solutions with concrete or to remove unsuitable materials that are replaced with masses of the desired quality. Both of these solutions will have a higher carbon footprint.

The environmental challenges are mainly related to two issues according to Müller & Saathoff (2015); plastics in the environment, especially in the ocean, and emission of additives and their degradation products from the polymeric material into the environment, which might be unhealthy or may have some ecotoxic effects.

A problem regarding plastics in nature is to get data on how it is transported. It has been estimated that 35.2 kilotonnes of plastic debris exists in the surface waters of the ocean (Cózar et al. 2014). This is regarded as a conservative high estimate. Geosynthetics have most likely contributed to this number. By how much is hard to say. This happens as geosythetics become brittle with aging, so it is both an environmental and mechanical problem.

Cózar et al. (2014) states that a polypropylene nonwoven geotextile properly stabilized with hindered amine antioxidants of high molecular weight, which is applied in an underwater construction, where the supply of oxygen is limited and the temperature is constantly on a low level, will last at least for one hundred years. However, the same product will fail within a few decades if poor antioxidant packages are used.

The additives used in geosynthetics may be harmful to humans. This is mainly caused by plasticizers as phthalates. Low phthalates are being phased out by most countries due to its' health issues.

# Chapter 4

# Geotextiles based on natural material

The precursors of today's geotextiles were based on natural fibers. Wood, bamboo, reeds and skins have been used in conjunction with soils for thousands of years (Kennedy & Parveen 2007). Natural materials are still in use today although synthetics rule the market. Especially in countries as India, Bangladesh, China and other Asian countries where the material grows it is common to use.

## 4.1 Materials

Desai and Kant separates natural fibers into plant based, animal based and mineral based as shown in Figure 4.1 (Desai, Kant). Animal based fibers could be wool or silk. Mineral fibers could be asbestos or basalt.

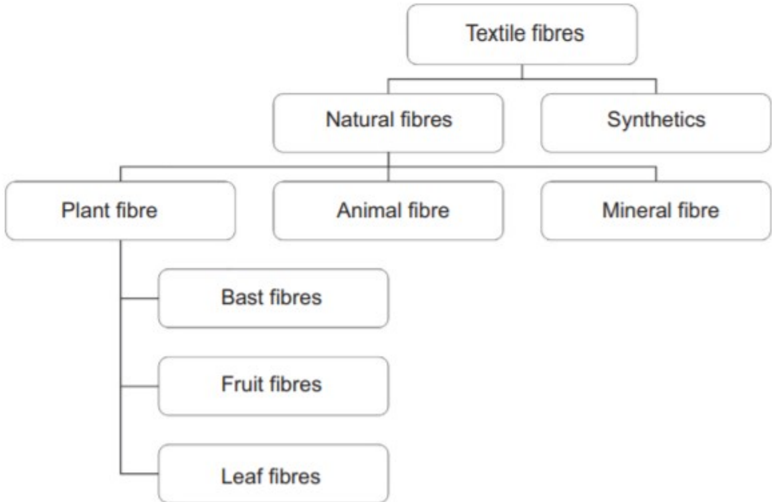



Figure 4.1: Classification of natural textile fibers (Desai, Kant)

Plant fibers contains cellulose which is dominant for many of the properties. The plant fibers can be subdivided into bast fibers, fruit fibers and leaf fibers, based on where on the plant they are extracted.

Typical bast fibers are jute, hemp and flax. The fibers are extracted from the plant by a microbial process named retting. Both long fibers and short, coarser fibers are products of the process. The long fibers are used in geotextiles, and can be used in both woven and non-woven products. Jute and coir based products are dominating the commercial market. Geotextiles made from jute and coir are shown in Figure 4.2.

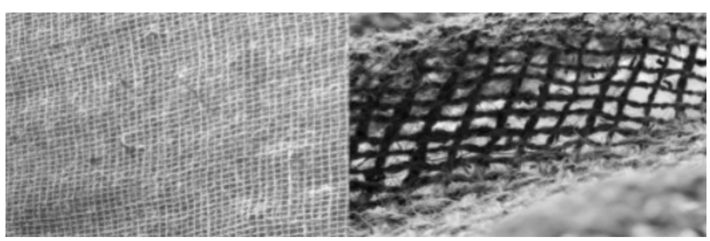


Figure 4.2: Geotextiles made from jute (left) and coir (right) (H. Wu et al. 2020)

Coconut fiber is the most common fruit fiber. A retting process is also used to extract the fibers from the coconut, after the skin or husk has been separated from the nut. Geotextiles based on coconut husk is an emerging product for erosion control of soil slopes according to Singh et al. (2006).

Leaf fibers are known to be harder and less flexible than bast fibers. They are extracted form leaves, but not by a retting process. The process to obtain fibers from leafs is called decortication. It involves scraping pulp form the fibers by a knife in a mechanical or manual matter.

## 4.2 Typical material parameters for geotextiles based on natural material

Natural fibers, especially plant based, are preferred in constructions where their application is only short term. Typical service life is 6 months to 10 years (Kennedy & Parveen 2007). Their biodegradability is one of the most important aspects then.

The most important constituents for plant based natural fibers are cellulose, lignin, hemicellulose and pectin. Typical values for jute and coir are given i Table 4.1 (Desai, Kant):

Table 4.1: Chemical composition of jute and coir in percentage by weight (Desai, Kant)

| **Fiber** | **Cellulose [%]** | **Lignin [%]** | **Hemicellulose [%]** | **Pectin [%]** |
|---|---|---|---|---|
| Jute | 58-63 | 12-14 | 21-25 | 0.5-1.5 |
| Coir | 43.44 | 45.84 | 0.25 | 3.3 |

The composition of these in the used fibers are important for their properties. Regarding lifespan for the product, the quantity of cellulose and lignin plays an important role. The expected service life for jute is one year if it is not treated, two years if treated with rot-resistant agents and four years when treated with bitumen (Desai & Kant 2016). Shukla (2002) states that jute geotextiles will degrade completely in two years. Lignin and hemicellulose controls degradation caused by UV or biologic material, thermoplasticity, moisture sensitivity and flammability. An overview of the properties of these fibers are given in Table 4.2:

Table 4.2: Properties of jute and coir (Desai, Kant)

| **Property** | **Jute** | **Coir** |
|---|---|---|
| Density [$g/cm^3$] | 1.46 | 1.2-1.4 |
| Fineness, denier | 13-30 | 162-450 |
| Length [cm] | 150-360 | 5-20 |
| Colour | Brown | Dark brown |
| Volume swelling in water [%] | 44.5 | - |
| Moisture absorption at 65 % RH [%] | 13.8 | 10.5 |
| Tensile strength [MPa] | 393-773 | 100-220 |
| Tensile modulus [GPa] | 26.5 | 3-10 |
| Elongation at break [%] | 1.5-1.8 | 15-30 |

## 4.3 Advantages and challenges with geotextiles based on natural material

The most important challenges for natural based geotextiles is the tensile strength and degradation properties. As Desai and Kant states; "The short life of natural geotextiles is a matter of concern for end users but their eco-compatability gives them an edge over man-made geotextiles" (Desai and Kant).

Whether the short service life is a disadvantage or not is totally dependent on the use of the product. If the intended use is for reinforcement it is challenge. If the intended use is for filtration and separation it may not be.

Microorganisms in soil combined with water makes the natural fibers degrade. Jute fibers have a shorter expected service life than coir due to their content of lignin. The products can be treated with protective coatings to slow down the process. If this is done, the service life will be extended and the products can be used in short- and medium-term applications, typical reinforcement applications for roads. Another alternative is to make a blend of natural fibers and synthetic fibers. This will improve the durability and extend the field of application. It is common for jute products to be treated with bitumen or rot-resistant chemicals as mentioned.

For the coconut based products, studies has been carried out by Singh et al. (2006). Tensile tests of four types of biodegraded woven geotextiles were carried out. It was found that the products remained unaffected in water and clay after six months. In an aerobically decomposed manure environment the tensile strength of the products was considerably reduced.

Plant based fibers are often produced in developing countries. A lot of individuals are employed in that way. Some of the natural fibers, as coconut husk, may be a residual product. To take this into use will be a step in a sustainable direction. Depending on where in the world the products are produced, transportation and production may be a challenge.

There is a number of benefits in using natural geotextiles. The main challenge is whether or not they reach the required properties.

# Chapter 5

# Geotextiles based on basalt

There is not done much work on basalt geotextiles. A study on how fibers of different lengths mixed with silt behaves in unconsolidated undrained triaxial tests has been carried out but doesn't have much transfer value to basalt geotextiles (Ndepete & Sert 2016). Some products can be found online on manufacturers websites. However they don't provide the strength properties of the products.

Basalt fiber may solve the degradation and strength problems of other natural fibers. The idea of extruding fibers from basalt came from Paul Dhé. He was granted a patent in 1923 for this. Around 1960, both the US and Soviet began to study the use of basalt fibers, especially for military purposes. The material has good strength properties and fire properties. However the US manufacturers chose to improve the performance of glass fibers and other fibers that they already produced instead of basalt fiber (Ross 2006). Countries in Eastern Europe continued the research on basalt. Today most of the production and research is done in these countries. However China has a production, as well as Texas and Belgium (Ross 2006). In Norway the company ReforceTech has some products based on basalt. They are mainly products for reinforcement of concrete. They also have a geogrid based on basalt but there is hardly any information available on it.

In other industries it is more used. It is used by the boat industry instead of glass fiber, in the building industry as reinforcement fibers in concrete, in industries where its' fire properties come to use as in the automotive industry and in the medical industry, to name a few.

## 5.1 Production

Basalt is a dark, fine-grained lava rock that mainly consists of calcium-rich feldspar (plagioclase) and pyroxene (augite). Smaller amounts of olivine or quartz may also occur (Faggruppe for geoteknikk NTNU 2018). It is the earth's most widespread day rock.

It is such a melt that flows out along the large volcanic mountain ranges on the seabed. Our seabed thus consists of a large part of basalt. When the Oslo field burst almost 300 million years ago, basaltic lava came to the surface. That is why the Oslo area is rich in basalt rock (Neumann et al. 1992).

As it is one of the most common surface rocks it should be a large yet relatively untapped resource. It should also be relatively easy to find. This can be a good starting point for fiber production.

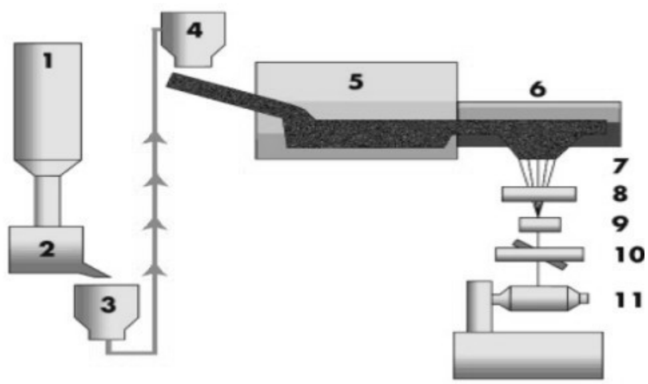



Figure 5.1: Simple scheme of basalt production (Singha 2012)

The production process is simply explained in Figure 5.1. The steps in the process are: 1) Stone is crushed and put in a silo, 2) loading station, 3) transport system, 4) batch charging station, 5) initial melt zone, 6) secondary controlled heat zone, 7) filament forming, 8) sizing applicator, 9) strand formation, 10) fiber tensioning, and 11) winding.

Fibers or strands may be used in the products. Rebars have been made and used in concrete technology. Ropes can be made as well which makes it possible to make quite strong products. In Figure 5.2 a rope of 5 mm made from basalt is shown.


Figure 5.2: The structure of a rope of 5 mm made from basalt (Quagliarini et al. 2012)

Figure 5.3 shows a geotextile made from basalt.

Figure 5.3: Geotextile made from basalt (Kumbhar 2014)

## 5.2 Typical material parameters

As a construction material, basalt finds itself among glass, carbon and aramid fibers (Quagliarini et al. 2012; Kumbhar 2014; Ross 2006).

A comparism on mechanical properties for basalt fibers compared to polyamide, jute and coir is given in Table 5.1 based on existing literature (Ross 2006; Jamshaid & Mishra 2016; Singha 2012; Dhand et al. 2015; Kumbhar 2014).

Table 5.1: Mechanical properties of basalt compared to polyamide, jute and coir

| Parameter | Basalt | Polyamide | Jute | Coir |
|---|---|---|---|---|
| Tensile strength [MPa] | 3000-4840 | 2900-3450 | 393-773 | 100-220 |
| Elastic modulus [GPa] | 79.3-93.1 | 70-140 | 26.5 | 3-10 |
| Elongation at breakage [%] | 3.1-6 | 2.8-3.6 | 1.5-1.8 | 15-30 |
| Specific gravity [] | 2.65-2.8 | 1.44 | 1.29 | - |

Although it may not be the most interesting property of basalt for geotechnical engineering, it has excellent thermal resistance (Kumbhar 2014). In some applications it may be important. If the material in the future will be used in road applications and needs to withstand high temperatures from asphalt it will come to use.

Basalt has been in nature for thousands of years. It has excellent chemical resistance. It can withstand alkaline environments with pH up to 13 or 14 or environments with low pH. It is not sensitive to salts. The material is not reactive with water, air or gases (Kumbhar 2014).

As the material has a large specific gravity it means it is quite dense. About 1 % moisture content is normal, meaning it is not porous. This property is of interest when we want to asses the hydraulic properties. It also causes fungi and micro-organisms not to thrive in the basalt environment. This may be of interest for clogging.

## 5.3 Advantages and challenges with basalt

As the deposits of basalt are large the material is relatively inexpensive. This makes a good foundation to make the basalt industry grow.

Another advantage is that it is a raw material. There are no known health issues related to the material. This point needs extensive research. At first it was not thought that asbestos was dangerous either, but it turned out to be completely wrong. Mechanical decomposition seems to be of higher importance than chemical as it is not considered as reactive. It is not organic and will not degrade like jute or coir that has a relative short service life. Nor will it degrade like synthetics.

A proper investment in the material is needed to make the industry grow. This could have happened in the 60s and 70s if there was a will. The basalt industry could have looked quite different today if that was the case. Such an investment is both time- and asset-consuming.

A clear advantage for the material is its' sustainable nature. It is relatively easy to obtain and there is a lot of it on earth. It doesn't put anything into nature that wasn't there from before and in that way it should not harm the ecosystems. Most likely it will act like soils do when it is decomposed and put into the cycle of nature again.

# Chapter 6

# Summary and Recommendations for Further Work

## 6.1 Summary and Conclusions

This literature study has examined the current use of geotextiles in geotechnical engineering. Out of all the possible uses it has been paid a special attention to products used for reinforcement and erosion control purposes. Basic aspects on these uses has been found, as how the forces are transmitted from soil to textile in reinforcement functions and basic calculations on hydraulic properties. Various standards and test methods exists. The European ones have been examined and some of them briefly explained.

A lot of attention has been paid to the materials that are used in geotextiles. Most products are made from synthetic materials. Natural materials exists. Jute and coir have been the most common ones and they have been around for a long time. Mechanical parameters for these materials have been investigated. Eventually basalt has been assessed. It is found that basalt has strength properties much like classical composite materials as glass, carbon and aramid. It has better mechanical properties for reinforcement purposes compared to organic materials. The decomposition of basalt is more like synthetic materials than organic. It will break into fragments and it will stay in the ecosystem which is also the case for synthetics. Organic material will degrade within a few years unless they are treated. In the ecosystem basalt and synthetics do not act the same. Basalt is natural and will not interfere the balance of nature. Synthetics will, and they do.

Based on all literature read it is believed that basalt geotextiles will be a suitable product for both reinforcement and erosion control purposes. This will most likely be further investigated in a master's thesis.

## 6.2 Recommendations for Further Work

As the use of basalt fibers in geotextiles is an immature technology, extensive research should be done to understand its' pros and cons.

The behaviour of the basalt based geotextile is fairly unknown. To understand its' failure mechanisms and particular behaviour, tests have to be done. The tests and specifications are already made and are discussed in Chapter 2.3. The job is to put all the existing products to test to gain knowledge and data.

Laboratory tests give valuable data on material behaviour but they doesn't always capture all necessary information on how it will act in real life situations. Full scale models with different research purposes should be built to understand this. When the material is taken in use in real life applications, it would be valuable to get test data from these projects. The more quality data, the better understanding.

There is also uncertainties regarding what will happen to the basalt fibers as the fabric decomposes. Does it act like plastic does, and if so, where will the fibers end up in the ecosystem? How will the material chip up? It is not guaranteed that basalt is better for the environment and ecosystems in that manner. It is recommended to do research on this.

# Bibliography


[1] Bentley Group. *PLAXIS 2D - Reference manual*. 2021.

[2] D. T. Bergado, P. V. Long & B. R. S. Murthy. “A case study of geotextile-reinforcedembankment on soft ground”. In: (2002).

[3] D. Bérubé & P. Saunier. “Manufacturing process of geotextiles”. In: *Geotextiles*. Ed. by R. M. Koerner. Woodhead Publishing, Jan. 1, 2016.

[4] L. D. Bloom. “On the relationship between layup time, material properties and mould geometry in the manufacture of composite components”. PhD thesis. Feb. 13, 2015.

[5] R. Bonaparte, R. D. Holtz & J. P. Giroud. “Soil reinforcement design using geotextiles and geogrids”. In: *Geotextile Testing and the Design Engineer, ASTM STP 952*. Philadelphia, PA, 1987.

[6] B. B. Broms. “Design of fabric reinforced retaining structures”. In: *Proceedings of the Symposium on Earth Reinforcement*. 1978.

[7] A. F. Claybourn & J. T. H. Wu. “Geosynthetic-Reinforced Soil Wall Design”. In: (1993).

[8] J. G. Collin. “Earth wall design”. PhD thesis. Berkeley, CA: Department of Civil Engineering, University of California, 1986.

[9] A. Cózar, F. Echevarrıa, J. I. González-Gordillo, X. Irigoien, B. Úbeda, S. Hernández-León, Á. T. Palma, S. Navarro, J. Garcıa-de-Lomas, A. Ruiz, et al. “Plastic debris in the open ocean”. In: *Proceedings of the National Academy of Sciences* 111.28 (2014).

[10] A. N. Desai & R. Kant. “Geotextiles made from natural fibres”. In: *Geotextiles From Design to Applications*. 2016.

[11] V. Dhand, G. Mittal, K. Y. Rhee, S.-J. Park & D. Hui. “A short review on basalt fiber reinforced polymer composites”. In: *Composites Part B: Engineering* 73 (May 1, 2015).

[12] Elwood. *A Report on the Comparative Advantages of Sisal, Coir and Jute Geotextiles*. 2004.

[13] R. D. Espinoza. “Soil-geotextile interaction: Evaluation of membrane support”. In: *Geotextiles and Geomembranes* 13.5 (Jan. 1, 1994).

[14] Faggruppe for geoteknikk NTNU. *Introduksjon til geoteknikk*. Trondheim, 2018.

[15] R. C. Hale, M. E. Seeley, M. J. La Guardia, L. Mai & E. Y. Zeng. “A Global Perspective on Microplastics”. In: *Journal of Geophysical Research: Oceans* 125.1 (2020).

[16] A. A. Horton & S. J. Dixon. “Microplastics: An introduction to environmental transport processes”. In: *WIREs Water* 5.2 (2018). _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/wat2.1268, e1268. ISSN: 2049-1948. DOI: 10.1002/wat2.1268. URL: https://onlinelibrary.wiley.com/doi/abs/10.1002/wat2.1268 (visited on 12/19/2021).

[17] Y. Hsuan, H. Schroeder, K. Rowe, W. Müller, J. Greenwood, D. Cazzuffi & R. Koerner. “Long-term performance and lifetime prediction of geosynthetics”. In: *Proceeding of EuroGeo 4-4th European Geosynthetics Conference*. 2008.

[18] T. S. Ingold & K. S. Miller. *Geotextiles handbook*. London, 1988.

[19] ISO. *ISO 13431 Geotextiles and geotextile-related products — Determination of tensile creep and creep rupture behaviour*. 1999. URL: https://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=115172.

[20] ISO. *ISO 12236 Geosynthetics — Static puncture test (CBR test)*. 2006. URL: https://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=195307.

[21] ISO. *ISO 13433 Geosynthetics — Dynamic perforation test (cone drop test)*. 2006. URL: https://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=185808.

[22] ISO. *ISO 10319 Geosynthetics — Wide-width tensile test*. 2015. URL: https://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=750402.

[23] ISO. *ISO 13438 Geosynthetics — Screening test method for determining the resistance of geotextiles and geotextile-related products to oxidation*. 2018. URL: https://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=1008039.

[24] ISO. *ISO 10722 Geosynthetics — Index test procedure for the evaluation of mechanical damage under repeated loading — Damage caused by granular material (laboratory test method)*. 2019. URL: https://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=1101083.

[25] ISO. *ISO 11058 Geotextiles and geotextile-related products — Determination of water permeability characteristics normal to the plane, without load*. 2019. URL: https://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=1040211.

[26] ISO. *ISO 12956 Geotextiles and geotextile-related products — Determination of the characteristic opening size*. 2019. URL: https://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=1109561.

[27] H. Jamshaid & R. Mishra. *A green material from rock: basalt fiber–a review*. Vol. 107. 7. Taylor & Francis, 2016.

[28] H.-Y. Jeon. “Geotextile composites having multiple functions”. In: *Geotextiles*. 2016.

[29] J. F. Kennedy & Z. Parveen. *Biodegradable and Sustainable Fibres*. 2007.

[30] R. M. Koerner. *Designing with Geosynthetics - 6Th Edition Vol. 1*. Xlibris Corporation, Jan. 16, 2012.

[31] R. M. Koerner. “Early background and history of geotextiles”. In: *Geotextiles From Design to Applications*. 2016.

[32] R. Koerner. *Geotextiles: From Design to Applications*. Woodhead Publishing, Feb. 11, 2016.

[33] V. P. Kumbhar. “An Overview: Basalt Rock Fibers - New Construction Material”. In: (2014).

[34] D. Leshchinsky & E. B. Perry. “A design procedure for geotextile-reinforced walls”. In: Proceedings of the Geosynthetics "87 Conference. Vol. 1. New Orleans, 1987.

[35] W. W. Müller & F. Saathoff. “Geosynthetics in geoenvironmental engineering”. In: *Science and technology of advanced materials* (2015).

[36] C. P. Ndepete & S. Sert. “Use of Basalt Fibers for Soil Improvement”. In: *Acta Physica Polonica Series a* 129 (2016).

[37] E.-R. Neumann, K. Olsen, W. Baldridge & B. Sundvoll. “The Oslo rift: A review”. In: *Tectonophysics* 208.1-3 (1992).

[38] NorGeoSpec. *NorGeoSpec 2012*. 2012.

[39] R. K. Penny & D. L. Marriott. *Design for Creep*. Springer Science & Business Media, Dec. 6, 2012.

[40] F. Petersen & J. A. Hubbart. “The occurrence and transport of microplastics: The state of the science”. In: *Science of The Total Environment* 758 (Mar. 1, 2021).

[41] E. Quagliarini, F. Monni, S. Lenci & F. Bondioli. “Tensile characterization of basalt fiber rods and ropes: A first contribution”. In: *Construction and Building Materials* 34 (2012).

[42] P. Rimoldi. “Geotextiles used in reinforcing walls, berms, and slopes”. In: *Geotextiles From Design to Applications*. 2016.

[43] Y. Rogbeck, C. Alén, G. Franzén, A. Kjeld, K. Odén, H. Rathmayer, A. Watn & E. Øiseth. “Nordisk håndbok armert jord og fyllinger”. In: (2006).

[44] A. Ross. “Basalt Fibers: Alternative to Glass?” In: *Composites Technology* 12.4 (Aug. 2006).

[45] G. R. Schmertmann, V. E. Chouery-Curtis, R. D. Johnson & R. Bonaparte. “Design charts for geogrid-reinforced soil slopes”. In: Proceedings of the Geosynthetics ’87 Conference. New Orleans, 1987.

[46] S. K. Shukla & J.-H. Yin. “Fundamentals of Geosynthetic Engineering”. In: (1987).

[47] S. K. Shukla. *Geosynthetics and their applications*. Thomas Telford Publishing, Jan. 1, 2002.

[48] R. M. Singh, G. Venkatappa Rao & H. R. Thomas. “Sustainable development: Durability of natural geotextiles as erosion control product | 5th ICEG Environmental Geotechnics: Opportunities, Challenges and Responsibilities for Environmental Geotechnics”. In: *Sustainable development* (2006).

[49] K. Singha. “A Short Review on Basalt Fiber”. In: *International Journal of Textile Science* (2012).

[50] C. J. Sprague & J. E. Sprague. "Geosynthetics in erosion and sediment control". In: *Geotextiles From Design to Applications*. 2016.

[51] Standard Norge. *NS 12224 Geotekstiler og geotekstilrelaterte produkter - Bestemmelse av motstand mot forvitring*. 2000. URL: https://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=1376197.

[52] Standard Norge. *NS 13251 Geotekstiler og geotekstilrelaterte produkter - Krav til egenskaper ved grunnarbeider, fundamenter og støttekonstruksjoner*. 2016. URL: https://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=871006.

[53] Standard Norge. *NS 12447 Geotekstiler og geotekstilrelaterte produkter — Utsilingsprøving for bestemmelse av motstand mot hydrolyse i vann*. 2021. URL: https://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=1376197.

[54] Standard Norge. *NS ICS 59.080.70 Standardsamling for geotekstiler*. 2021. URL: https://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=248306.

[55] J. E. Steward, R. Williamson & J. Mohney. "Earth reinforcement". In: *Guidelines For Use of Fabrics in Construction and Maintenance of Low- Volume Roads*. Vol. 5. Portland, Oregon: Forest Service, 1977.

[56] H. Vidal. "The Principle of Reinforced Earth". In: *Highway Research Record* 282 (1969).

[57] H. Wu, C. Yao, C. Li, M. Miao, Y. Zhong, Y. Lu & T. Liu. "Review of Application and Innovation of Geotextiles in Geotechnical Engineering". In: *Materials* 13.7 (Jan. 2020).

[58] H. Zanzinger. "Mechanical properties, behavior, and testing of geotextiles". In: *Geotextiles From Design to Applications*. 2016.

Henrik Faye

Geotextiles and geogrids based on basalt

NTNU
Norwegian University of
Science and Technology