

## Deliverable D3.6

# High Temperature Composite Casing

## List of Requirements & Technical Specifications

|                        |   |      |         |
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## Executive summary

This is the first draft of the List of Requirements and Technical Specifications (LoR) for the temperature upgrade of the advanced composite casing system of Akiet BV.

During the GeoWell project, through the research activities and cooperation with various specialists, new insights will be gained and the LoR document will be further supplemented and improved. Based on the final version of the LoR, the High Temperature resistant Composite Casing (HTCC) system will be developed, build and tested in the Akiet workshop. If possible, a field trial will be prepared and executed.

In the introduction, the purpose of the document is explained

This draft version is a public version. Later versions, when more detailed Technical Specifications are added, the LoR will be classified and only accessible to the GeoWell project partners and the strategic consortium partners of Akiet (stakeholders).

In order for the GeoWell project partners to better understand the background and objective of the Akiet R&D work, a concise presentation and explanation of Akiet and the advanced composite casing systems is given.

Next, a so-called process-tree is presented. The application process tree serves as a tool to prepare the list of requirements and technical specifications of the HTCC system (pipe body and connections). Going through the entire life cycle process, from production to abandonment, reduces the chance that product requirements will be overlooked.

In the List of Requirements section the first requirements are compiled, as yet no priority indication is given.

As a starting point for the LoR two possible concept well designs were chosen. The load cases from the installation and exploitation of these wells were determined and the extremes represent the distinctive load cases on which the requirements are based.

## List of Abbreviations (Alphabetical order)

|      |   |
|------|---|
| BHA  | Bottom Hole Assembly                            |
| CWD  | Casing While Drilling                           |
| ECCI | Enhanced Composite Casing Installation          |
| ECI  | Enhanced Casing Installation                    |
| ESP  | Electrical Submersible Pump                     |
| FEA  | Finite Element Analysis                         |
| FEM  | Finite Element Modelling                        |
| GRP  | Glass fiber Reinforced Polymer                  |
| HSCC | High Strength Composite Casing                  |
| HSCT | High Strength Composite Tubular                 |
| HTCC | High Temperature Composite Casing               |
| LoR  | List of Requirements & Technical Specifications |
| MCI  | Metal Composite Integration                     |
| NCF  | Non Crimp Fabric                                |
| O&G  | Oil & Gas                                       |
| R&D  | Research & Development                          |
| RCM  | Rotational Casting Manufacturing                |
| RT   | Room Temperature                                |
| ST   | Service Temperature                             |
| TD   | Target Depth                                    |
| TOC  |   |
| TVD  |   |

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## 1 Introduction

The document before you is the (first) draft version of the List of Requirements & Technical Specifications of the High Temperature Composite Casing system of Akiet BV.

### 1.1 Purpose of This Document

This document is intended to guide the Research & Development of **the High Temperature Composite Casing (HTCC) system** in the framework of the GeoWell project.

The approved document will be the basis for the contribution of Akiet in the GeoWell project; the research & development of a HTCC system for ultra deep geothermal applications (target depth  $\geq 3500$  meters).

The List of Requirements and Technical Specifications (LoR) will go through several stages during the course of the GeoWell project:

1. **Draft:** The first version, or draft version, is compiled after requirements have been discovered, recorded, classified, and prioritized.
2. **Proposed:** The draft document is then proposed as a potential requirements specification for the project. The stakeholders can review the proposed document and comment on any requirements and priorities, or identify missing requirements. The document may be amended and re-proposed several times before moving to the next stage.
3. **Validated:** Once the various stakeholders have agreed to the requirements in the document, it is considered validated.
4. **Approved:** The validated document is accepted by representatives of each party of stakeholders as an appropriate statement of requirements for the project. The developers then use the requirements document as a guide to implementation and to check the progress of the project as it develops.

The draft version is a public document. The proposed version will be confidential and only accessible to the stakeholders, which are: the GeoWell project partners and the strategic consortium partners of Akiet.

## 2 Akiet BV (Akiet)

Akiet is the manufacturer of the High Strength Composite Casing (HSCC) systems for down-hole applications. The systems are manufactured with the Rotational Casting Manufacturing (RCM) process, which was developed by Akiet over the past three years. The RCM process makes use of very high G-forces to impregnate the glass fibers with epoxy resin and has resulted in an unprecedented high quality laminate.

The Akiet composite tubular systems are characterized by:

- Smooth inner and outer surface
- Very accurate dimensions
- Near perfect laminate (zero inclusions)
- Possibility of  $\pm 45$  to 0/90 degree fiber orientation

The high quality of the RCM laminate creates new requirements for materials and suppliers. The upgrade to higher temperatures will imply modifications of the composite materials (glass fibers and epoxy resin) and the adhesive, but also of the RCM production process, the RCM production line, the design of the connections and the connection process.

Since Akiet has decided not to disclose any information about the RCM production process, this document will only contain the requirements and technical specifications of the composite casing and the connection design and process.

The List of Requirement & Technical Specifications is a so called living document, which means that will be elaborated, improved, modified and completed throughout the entire duration of the GeoWell project. The set-up is as follows:

- Description of the product (High Temperature Composite Casing)
- Description of the application of the product (application process tree) during the total life cycle of the product
- List of requirements of the product (High Temperature Composite Casing system)
  - Composite pipes (diameter, wall thickness, fiber architecture, protective inner and/or outer layers)
  - Composite pipe connections
    - Full composite connections
    - Metal to Composite Integration (MCI) connections
- List of specifications of the product materials, components and details
  - Glass fibers, glass fiber fabrics
  - Epoxy resins and hardeners
  - Adhesives full composite connections
  - Adhesives MCI connections

## 2.1 Vision

Akiet aims to be the enabler of next generation drilling applications by developing and producing custom-made composite tubulars for down-hole installation.

## 2.2 Mission

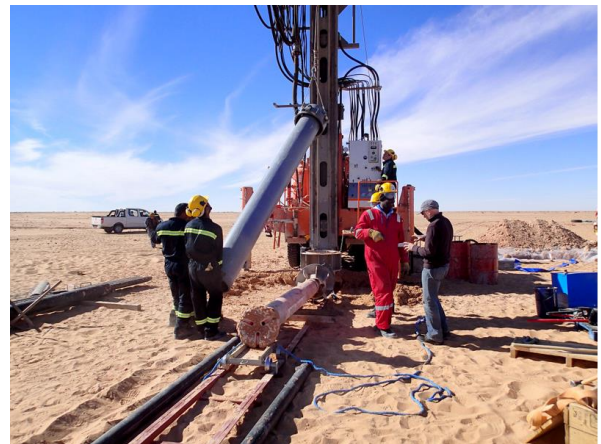
Akiet services customer needs for cheaper and more environmentally benign deep drilling applications. Its technology will combine the benefits of composite with operational requirements in deep-drilling operations to:

- Facilitate the exploitation of geothermal energy by reducing environmental impact, capital investment and operating costs
- Enable longer reach drilling operations, reducing operational risk, surface impact and costs
- Extend well life by eliminating corrosion and scaling
- Increase exploitation of reservoirs by enabling real time reservoir logging

## 2.3 History

Akiet was formed in April 2015 after combining technology developed in Acquit Business Development BV and funding from Ponooc Earth BV.

Born from combined experiences in O&G, solution mining and geothermal energy, Acquit Business Development BV was founded in The Netherlands, in 2001. During its first years, Acquit Business Development pursued a vision of “back of the truck drilling” and “drilling to 3000 meters (10,000 ft) depth from a parking lot” to enable the viability of geothermal energy exploitation.



*Figure 1: Back of the truck drilling*

Since 2008 Akiet (Acquit Business Development) and Well Engineering Partners BV<sup>1</sup> (WEP) have been working on the development of an innovative drilling technology, based on the combination of a simplified version of the patented casing while drilling technology (CWD) from the oil industry, and advanced lightweight composite casing systems. The technology

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<sup>1</sup> <http://wellengineering.nl/>

was named Enhanced (Composite) Casing Installation (ECI / ECCI), and is characterized by risk-mitigation, time and cost reductions and human safety.

WEP was responsible for the drilling technology, which can be applied with both steel and composite casing. The ECI / ECCI technology will lead directly to risk mitigation, timesaving and cost reduction. In 2012 WEP and Huisman Equipment BV<sup>2</sup> joined forces and founded Huisman Well Technology BV<sup>3</sup> (HWT) to further develop and roll out the technology.

Through the years the company combined with industrial partners, institutions and inventors to pursue this vision. With time, however, customers from other industries than geothermal energy realized the potential of Akiet High Strength Composite Casing and the Enhanced Composite Casing Installation (ECCI) for applications where steel falls short of expectations.

Since the second half of 2015 Akiet has started the construction and commissioning of a commercial manufacturing facility in Lelystad in the Netherlands.

## 2.4 Value proposition

Akiet does not provide generic wholesale products but custom fit solutions to customer needs. Its value proposition consists of five elements, which are discussed, in greater detail under Akiet Services.

1. Project and Well Design. Its well engineers work with the customer to determine the loads that the completion will be subjected to in the particular application. These will be different from the loads as determined for a well completed in steel because of the different and anisotropic properties of a composite completion.
2. Product design and R&D. From the agreed requirements of the tubulars the right design is determined. Using chemical impact simulations and with FEA the tubulars are designed with as major variables the fiber selection, the required amount of fibers in different orientations within the pipe body, the wall thickness and resin type.
3. Tubular production. All tubulars will be produced in Akiet's fully owned manufacturing facilities using our proprietary Rotary Casting Manufacturing technology. This gives full quality control and in combination with in-house testing capability ensures that product has the properties as agreed with the customer.
4. Connection Technology. Akiet uses fast curing adhesives in a custom designed collar coupling. These couplings are produced in-house and finished to tight tolerances by means of robotics.
5. Installation Services. Akiet engineers, fully qualified and certified for work on the drill floor assist the customer with correct installation of the completions to ensure proper installation while minimizing the training requirements of the customer.

Akiet does not just sell tubulars. It provides custom made solutions to the challenges that our customer needs to overcome.

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<sup>2</sup> [www.huismanequipment.com/](http://www.huismanequipment.com/)

<sup>3</sup> [www.huismanwelltechnology.com/](http://www.huismanwelltechnology.com/)

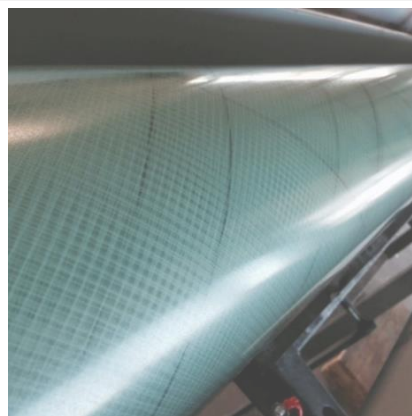
### 3 Akiet High Strength Composite Casing (HSCC) Systems

The current Akiet high strength composite casing (HSCC) systems consist of glass fiber reinforced polymers (GRP) pipes and collars. During the production in the factory the pipe ends are cone-shaped machined. The collars are adhesively bonded to one end of the pipes. This results in a pipe with a collar at one end, which is called a pipe joint.

The pipe joints are adhesively connected on-site (on the rig floor) during the casing installation or drilling operation. These on-site connections will have to be made and ready for operation as fast as possible. This includes fixating the pipe system, aligning the two pipe joints, injecting the adhesive, the curing process and releasing the pipe system for further installment. The lead-time for the on-site connections should be maximum 15 minutes.

The Akiet HSCC systems comprise of the following components:

- Glass-fiber reinforced polymer (GRP) pipes, with an average length of 12 meters
- Full composite connections
- Metal to composite connections (MCI = metal composite integration)
- Cross-overs, X-overs to connect the HSCC to the installation/drilling equipment
- Handling equipment (tooling interfaces)
- Installation equipment (alignment tool and adhesive injection tool)



Note:

*The dark and light crossed wires ( $\pm 45/45$  degrees) in the tube are not the glass fibers, but the stitching holding the glass fiber fabric together. The glass fibers are in axial and circumferential (hoop) direction (zero-ninety laminate, 0/90).*

**Figure 2: The Akiet High Strength Composite Casing**

The Akiet HSCC system will be used for the exploration & production of oil & gas, salt solution mining (minerals) and/or geothermal energy. Currently the service temperature for the HSCC systems is limited to 85-95°C.

### 3.1 Akiet & GeoWell

Akiet is beneficiary in the GeoWell project. The Akiet contribution in Work Package 3, Task 3.6 consists of the research and development of high temperature resistant composite casing system.

The objective of Task 3.6 is to upgrade the temperature resistance of the Akiet composite pipe systems. Akiet will divide the research in two separate trajectories:

- The upgrade of the Akiet high strength composite casing (HSCC) systems to service temperatures of 150-170°C (HSCC → HTCC), which has to be realized with the materials already used and processed by Akiet.
- The research of materials to develop high strength composite casing systems resistant to service temperatures of 250-300°C, which will require a total different line of (thermoplastic) polymers.

From now on only the term HTCC will be used.

### 3.2 HTCC connections

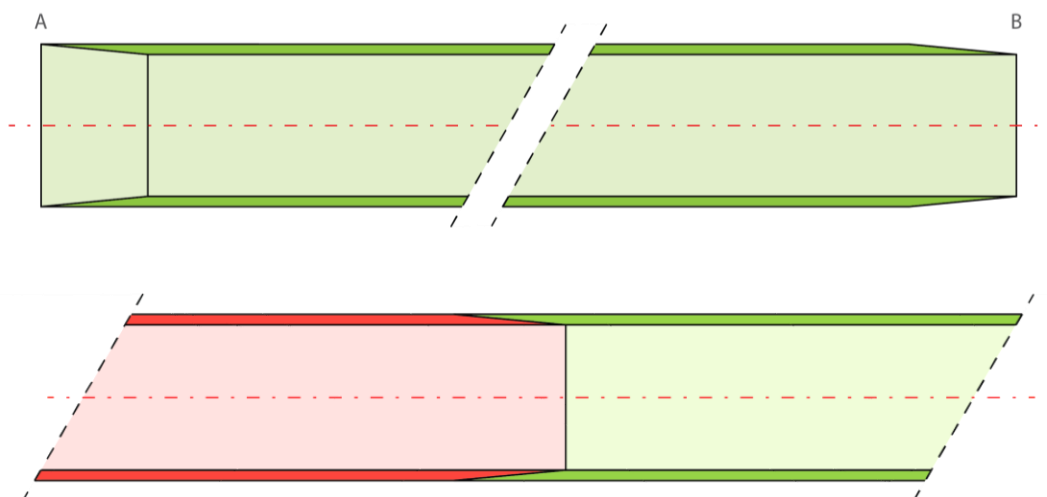
***“Basically the connection should not be the weakest part of the HTCC system”.***

Akiet distinguishes two kinds of full composite connections:

- a. the ‘scarf joint’ connection.
- b. the collar, or sleeve connection
- c. the metal to composite connection, the metal composite integration, or MCI

#### 3.2.1 Scarf joint connection

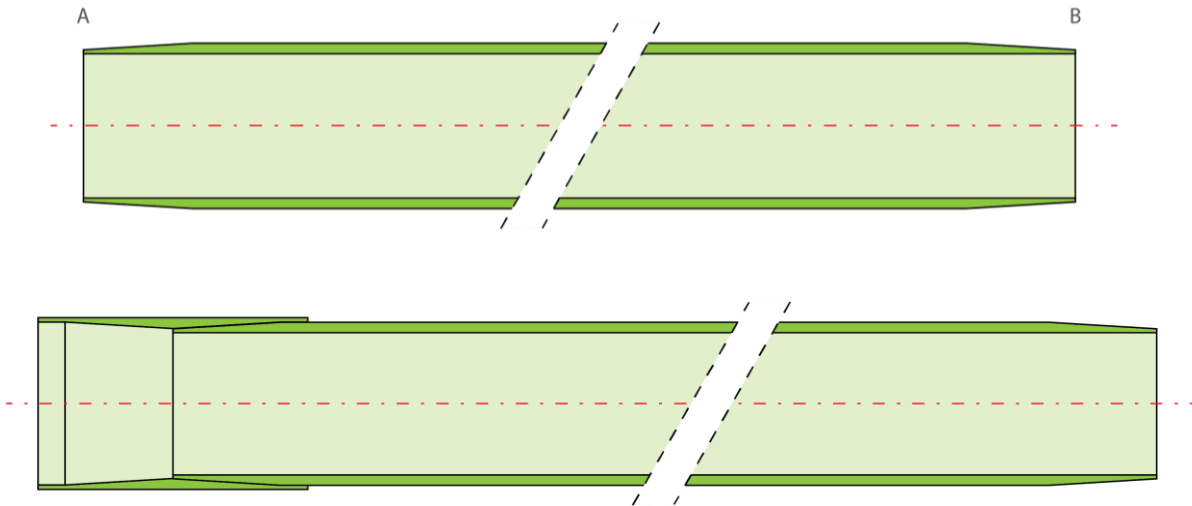
Scarf joints demand a cone-shaped pipe end like is shown in the first figure below. The pipes with the female (A) and male (B) endings are stacked and adhesively connected. The scarf joint is a fully flush connection. Because the cone-shaped machined pipe ends have a very small wall thickness (2 mm), the pipe ends are very vulnerable and have to be well protected.



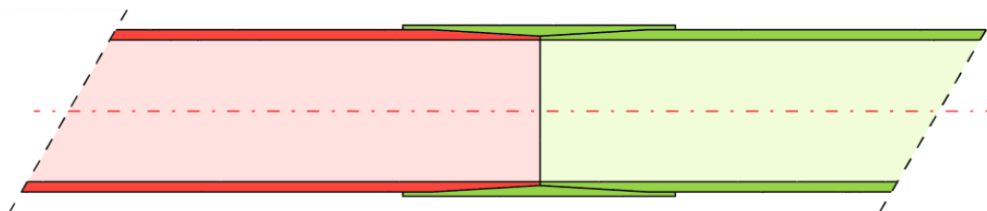
**Figure 3: the scarf joint connection**

### 3.2.2 The collar, or sleeve connection

The collared connections are more robust and easier to handle on the rig floor. First the collar is adhesively bonded in the factory to one end of the pipe body (see figure 4). This results in a pipe joint with a cone-shaped side at one end (male) and a collar at the other end (female). The larger diameter of the collar (upset) brings some additional advantages for the installation process. They protect the pipe body in the borehole and serve as a back-up safety feature in case the HTCC system slips through the grippers of the drilling rig.



*Figure 4: HTCC collar adhesively connected to the HTCC pipe body (factory connection)*



*Figure 5: On-site connection (of two HTCC pipe joints)*

The HTCC pipe joints are connected on the rig floor during the casing installation or drilling operation. These on-site connections will have to be ready for operation within about ten minutes. This includes the fixation of the pipe system, aligning the two pipe joints, injecting the two-component adhesive, the curing process and releasing the pipe system for further installment.

The adhesive connections and in particular the on-site connections are the most challenging parts of the HTCC system, because adhesive connections request careful preparation, conditioned environment and cure time, which is not easy to achieve on the rig floor.

The same will apply to the High Temperature Composite Casing (HTCC) system.

Another possible, but maybe more distant, solution for the connections will be the full-composite, threaded connection. This solution direction will also be elaborated in the list of requirements and technical specifications.



*Figure 6: Making the on-site adhesive connection*

## 4 Application process tree

The application process tree serves as a tool to prepare the list of requirements and technical specifications of the HTCC system (pipe body and connections). Going through the entire life cycle process, from production to abandonment, reduces the chance that product requirements will be overlooked.

### 4.1 Manufacturing phase (confidential)

- RCM production of HTCC pipes and/or HTCC joints
- Packaging / protection / preservation
- Storage in warehouse

### 4.2 Sales & transport to destination

- Sale
- Load in truck
- Road transport / shipping / air freight
- Unloading
- Storage on site

### 4.3 Installation phase

- Unpack, unwrap
- Grip, hold, grasp, clasp and handle (tooling interfaces)
- Positioning on drilling rig
- Making the connections (casing string / drilling mud)
- Releasing the casing string from the slips
- Continuing the installation or drilling process
- Preparing for next connection
- Fixation of casing string in slips
- Reaching target depths
- Retrieving the BHA (bottom hole assembly) through the HTCC
- Pressure testing
- Cementing the HTCC
- Drilling the next section through the installed HTCC.
- Installing the liner hanger (cross-over between subsequent sections)
- Completion of the well
- Installing the ESP

#### 4.4 Exploitation phase (depends on HTCC application)

- Field of application:
  - Exploration and production of Oil & Gas
  - Salt solution mining
  - Geothermal energy
- Scope of application:
  - Casing, tubing, liner, drill pipe
    - Extended reach
    - Corrosion & chemical resistance
    - See-through
- GeoWell application:
  - Geothermal ( $1.250\text{m} \leq \text{TD} \leq 5.500\text{m}$ )
    - Injection
    - Production

#### 4.5 Abandonment

- Cement, close, isolate the well
- Recycle components and materials

## 5 List of Requirements

Requirements can be divided into two categories:

- a) User requirements. These are requirements written from the point of view of end users, usually expressed in narrative form.
- b) System requirements. These are detailed specifications describing the functions the system must be capable of doing.

It is important that both categories are represented in the distinct product phases of the List of Requirements and Technical Specifications.

### 1. General

### 2. Production (confidential)

- a. Semi continuous glass fiber fabric winding station
- b. Epoxy resin mixing and injection unit
- c. High speed Rotational Casting Manufacturing centrifuge
- d. Pull tool
- e. High-precision multi-axis pipe-end machining robot

### 3. Packaging & Storage

### 4. Sales & Transport (ex works)

### 5. Handling of HTCC joints (tooling interfaces)

### 6. Installation

- a. Lifting
- b. Making the connections
- c. Drilling with composite casing
- d. Retracting the BHA
- e. Cementation
- f. Drilling through composite casing
- g. Installing the ESP

### 7. Exploitation

- a. Production
- b. Injection
- c. CO<sub>2</sub> injection
- d. Monitoring & research
- e. Wire-line operations
- f. Service & maintenance
- g. Chemicals
- h. Wire-line operations

### 8. Abandonment

## 5.1 General requirements:

### a. Material of the HTCC is GRP, or Glass-fiber Reinforced Polymer

- Epoxy Resin
- Glass-fiber Fabric (NCF: Non Crimp Fabrics)
- Lay-up: from  $\pm 45/45$  to  $0/90$  (axial–circumferential)
- Fiber content: 40-65 %vol

### b. The adhesives can be divided in adhesives for:

- Full composite connections
- Metal to composite connections (only in workshop / factory)
- Workshop (factory) connections:
  - Conditioned environment
  - Long curing times possible
- On-site (drilling rig floor) connections:
  - Non-conditioned / limited-conditioned environment (temperature, rain, wind, dust, mud, oil, ...)
  - Cure time on site connections:  $\leq 10$  min.

### c. Application method

- Indoor (workshop or factory)
- Outdoor application (land & sea)
  - At drilling rig / rig floor

### d. Service temperature (ST)

- From room temperature (RT) to 160-170°C

### e. Chemical resistance

- Oil
- Gas
- Geothermal water (salt water, up to 150 grams NaCl per liter)
- Mud (drilling mud, pH value 9-10)
- Cement slurry (pH value 12-13)
- Acid wash (15% HCL for a maximum 12 hours)
- Resistance to a wide range of acids, alkali, bleaches and solvents for the use in corrosive environments in the chemical processing industry

## 5.2 Production phase

### a. Semi continuous glass fiber fabric winding station

- Specifications of the fiber fabrics with regard to the winding process
  - Fiber material, grade
  - Fiber architecture (fiber lay-up)
  - Sizing (fiber coating for resin adhesion)
  - Stitches (material)
- Special requirements for winding easily and accurate onto the mandrel

### b. Epoxy resin mixing and injection unit

- Special requirements with regard to the viscosity, polymerization and curing of the epoxy resin and hardener

### c. High speed Rotational Casting Manufacturing centrifuge

- Special requirements for the fiber fabrics to unwind (to release itself) from the RCM mandrel and accurate placement in the centrifuge
- Temperature resistance of fiber fabrics ( $\geq 170^{\circ}\text{C}$ )
- Special requirements with regard to the viscosity, impregnation, fiber-resin adhesion, polymerization and curing of the epoxy resin and hardener

### d. Pull tool

- The semi-finished (HTCC) product should accommodate extraction from the centrifuge with a pull force of 800kN (non-adhesion to the inner wall of the centrifuge, controlled shrinkage, enough structural strength and grip)

### e. HTCC factory transportation system

- The semi-finished (HTCC) product should not be damaged (impact, clamp, scratch) in normal use by the tooling interfaces of the pull tool and the lifting and transportation equipment in the factory.

### f. HTCC cure and post-cure oven

- The HTCC should be suitable to perform at service temperatures of  $170^{\circ}\text{C}$  after the curing and post curing process.

### g. High-precision multi-axis pipe-end machining robot

- The HTCC should be suitable for high precision machining without losing structural integrity, or introducing initial cracks or weak spots.
- The HTCC material should be tough, flexible, or ductile enough to permit a wall thickness at the end of a scarf joint of 2 mm.

### h. HTCC factory connections

- The factory connections should not be weakest link of the HTCC system.
- The factory connections should comply with the requirements of the on-site connection, with the exception of the time limitation of 10 minutes.
- The connections must be able to withstand the load cases as laid down in the tables 1 and 2 below.

- The connections have to be gas and fluid tight.
- The connections should be resistant to all chemicals used in the installation, service & maintenance of geothermal wells and installations.

**i. Alignment tool**

- The design of the HTCC must accommodate on-site connection (handling, weather proof, alignment, adhesive injection, curing)
- The relatively weak HTCC endings should be well protected with pipe-end protectors, which are easy to remove prior to installation
- The HTCC connection must be suitable for the application of the appropriate alignment tool (yet to be developed)
- The HTCC connection must be able to withstand the mechanical load of the alignment tool (→ requirements for the alignment tool)

**j. Adhesive injection unit**

- The design of the HTCC must accommodate on-site connection (handling, weather proof, alignment, adhesive injection, curing)
- The relatively weak HTCC endings should be well protected with pipe-end protectors, which are easy to remove prior to installation
- The HTCC connection must be suitable for the application of the appropriate adhesive injection tool (yet to be developed)
- The HTCC connection design must have a provision for guiding the injected adhesive, so that it spreads over the entire surface to be bonded

### 5.3 Packaging & Storage

- a. The relatively vulnerable HTCC pipe ends need to be well protected against impact (falling, collision, bump).
  - Special HTCC pipe end protectors need to be designed and build.
  - The pipe end protector should be mounted fast and easy (< 10 seconds).
  - The pipe end protectors will normally be removed on the rig floor just before installation.
- b. The HTCC should be protected from overdoses of ultraviolet radiation in sunlight.
- c. The HTCC should be packed in protective racks or crates in such a way that it is impossible to touch each other.
- d. For longer-term storage or transportation, the HTCC pipes/joints special crates will be used, which can contain multiple HTCC pipes/joints.
- e. For larger quantities, the HSCC pipes/joints will be packed in special 40ft containers (opening from above and/or on the side).

## 5.4 Sales & Shipment

- a. The HTCC pipes/joints must have a label (preferably) at both ends with a unique product identification number (UPIN) and information about the:
  - Temperature resistance of fiber fabrics ( $\geq 170^{\circ}\text{C}$ )
  - Production company,
  - Date of production (can be within the UPIN),
  - Technical specifications,
  - Field of application,
- b. The HTCC should have an attractive appearance.
- c. The HTCC should not be too susceptible to impact, falling, or bumping
- d. The HTCC should be well protected to prevent damage
  - Protective layer
  - Pipe end protectors
  - Protective packaging
- e. The HTCC should have sort of an indication system, which enables quick and easy detection of internal structural damage.

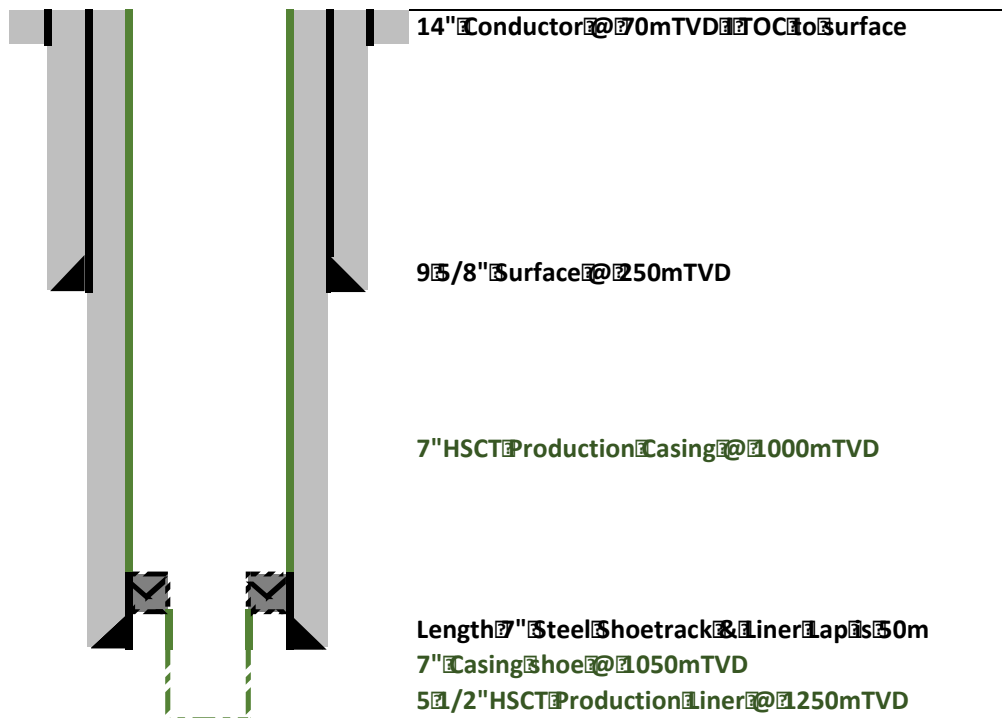
## 5.5 Handling of HTCC joints (tooling interfaces)

- a. The HTCC should not be damaged by the tools and handling equipment used in production, loading & unloading, installation and the service & maintenance during the exploitation phase of the well. Since the ruggedness of the composite materials is limited, the solution will have to be found in the HTCC and the handling equipment.
  - Protection of the HTCC itself: pipe end protectors and protective layers
  - Specially designed appropriate HTCC tooling interfaces

## 5.6 Installation & Exploitation

Two concept well designs have been chosen which will serve as a starting point to draw up the List of Requirements and Technical Specifications for the HTCC system:

- A geothermal well with target depth (TD) of 1250 meters and a service temperature (ST) at TD of 150°-170C,
- A geothermal well with TD of 5500 meters and ST of 150°-170°C.



*Figure 7: concept well design 1: TD 1250m / ST 150°-170°C*

Indicative load case of a 1250m deep well with a 7" HTCC production casing to TD of 1050m including 50m steel casing shoe.

Maximal mechanical load values for the 7" HTCC are:

- Burst: 234 bar
- Collapse: 102 bar
- Torsion: 3000 Nm
- Axial Tension: 705 kN
- Axial Compressive: 162 kN

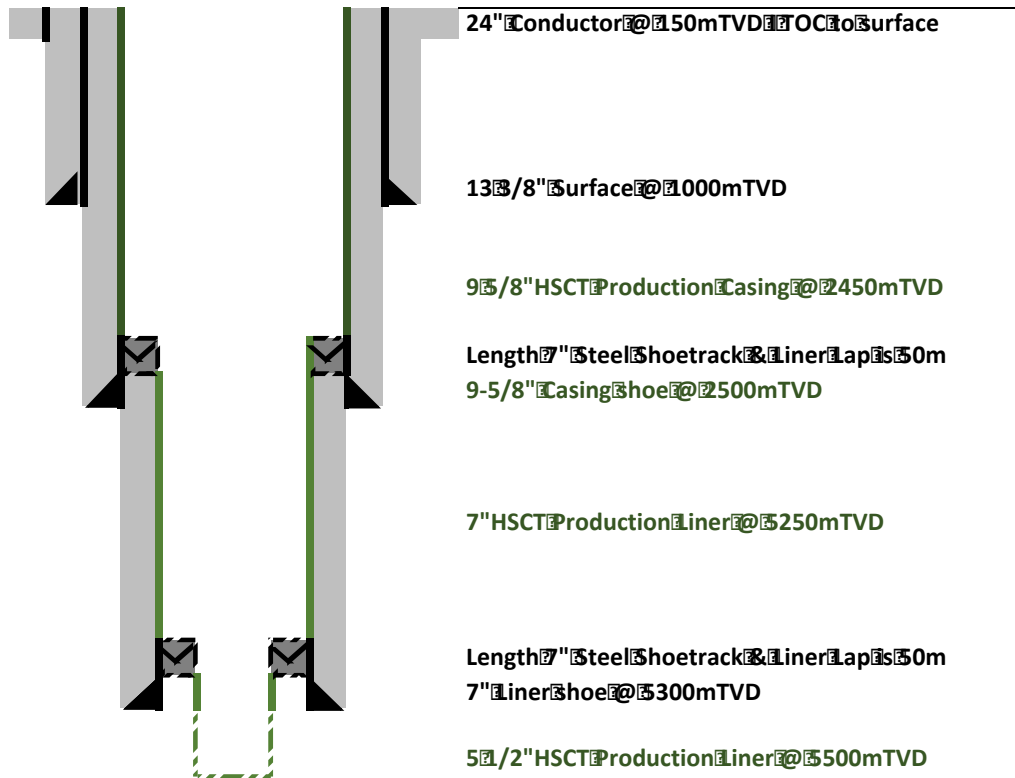


Figure 8: concept well design 1: TD 5500m / ST 150°-170°C

Indicative load case of a 5500m deep well with a 9-5/8" HTCC production casing to 2500m including 50m steel casing shoe.

Maximal mechanical load values for the 9-5/8" HTCC are:

- Burst: 240 bar
- Collapse: 176 bar
- Torsion: 3000 Nm
- Axial Tension: 1344 kN
- Axial Compressive: 278 kN

Indicative load case of a 5500m deep well with a 7" HTCC production liner from 2450m to 5300m including 50m steel casing shoe.

Maximal mechanical load values for the 7" HTCC are:

- Burst: 165 bar
- Collapse: 85 bar
- Torsion: 3000 Nm
- Axial Tension: 1147 kN
- Axial Compressive: 162 kN

| HTCC load case    | 7" HTCC | 9-5/8" HTCC | Units |
|-------------------|---------|-------------|-------|
| Burst             | 234     | 240         | [bar] |
| Collapse          | 102     | 176         | [bar] |
| Torsion           | 3000    | 3000        | [Nm]  |
| Axial tension     | 1147    | 1344        | [kN]  |
| Axial compression | 162     | 278         | [kN]  |

*Table 1: HTCC maximal load cases*

## 6 List of Technical Specifications of HTCC materials

### 6.1 HTCC connection design

Two kinds of connections are distinguished:

- Adhesive connection
- Mechanical, or treaded connection

The design of the connection should be optimized in a way that stress peaks are avoided, or within the prescribed standard (feasible specifications of chosen materials, see below).

The design depends on the following aspects:

- Choice of composite materials
- Choice of metals used for MCI
- Elongation differences of different materials due to mechanical loads
- Elongation differences of material thickness in design
- Temperature expansion differences
- Fiber architecture of HTCC pipe and connection sleeve
- Geometrical design of pipe end and connection sleeve.

### 6.2 HTCC glass fibers

- Glass fibers: grade, thickness, sizing
- Fabrics (weave, non-crimp-fabric, stiches material)

#### 6.2.1 Glass fiber data sheet:

- *Atomic Volume (average)*
- *Density*
- *Energy Content*
- *Bulk Modulus*
- *Compressive Strength*
- *Ductility*
- *Elastic Limit*
- *Endurance Limit*
- *Fracture Toughness*
- *Hardness*
- *Loss Coefficient*
- *Modulus of Rupture*

- *Poisson's Ratio*
- *Shear Modulus*
- *Tensile Strength*
- *Young's Modulus*
- *Glass Temperature*
- *Latent Heat of Fusion*
- *Maximum Service Temperature*
- *Melting Point*
- *Minimum Service Temperature*
- *Specific Heat*
- *Thermal Conductivity*
- *Thermal Expansion*
- *Breakdown Potential*
- *Dielectric Constant*
- *Resistivity*

### 6.3 HTCC epoxy resin

- Chemical composition (epoxy resin and hardener)
- Viscosity
- Adhesion to a wide variety of substrates
- Thermal cycling characteristics
- Flexibility
- Chemical and water resistance
- Tensile Strength, psi/MPa
- Elastic Modulus (Tensile, Young's), psi/GPa
- Elongation at break,
- Hardness,
- Compressive strength at yield, psi/MPa
- Glass Transition Temp. Tg(°F/°C)
- Cure properties

#### 6.3.1 Epoxy resin data sheet:

- **Liquid Properties:**
  - *Base Material Epoxy*
  - *Density Part A - Resin (g/ml)*
  - *Density Part B - Hardener (g/ml)*

- *Part A Viscosity (mPa s @ 20-23°C)*
- *Part B Viscosity (mPa s @ 20-23°C)*
- *Mixed System Viscosity (mPa s @ 20-23°C)*
- *Mix Ratio (Weight)*
- *Mix Ratio (Volume)*
- *Usable Life (20°C)*
- *Gel Time (23°C)*
- *Cure Time (23°C)*
- *Cure Time (60 °C)*
- *Cure Time (100 °C)*
- *Colour Part A – Resin*
- *Colour Part B – Hardener*
- *Storage Conditions*      *Dry Conditions: Above 15°C, Below 30°C*
- *Shelf Life*                      *24 Months (bulk) 18 months (resin pack)*
- *Exotherm*
- *Shrinkage*
  
- ***Cured System:***
  - *Thermal conductivity (W/mK)*
  - *Cured Density (g/ml)*
  - *Temperature Range (°C) (Application and Geometry Dependent)*
  - *Max Temperature Range (Short Term °C / 5 Mins)*
  - *Shore Hardness*
  - *Colour (Mixed System)*
  - *Flame Retardant*
  - *Coefficient of thermal expansion (ppm/°C)*
  - *Water Absorption*

#### **6.4 HTCC adhesive:**

- Chemical composition
- Tensile Strength, psi/MPa
- Elastic (Tensile, Young's) Modulus, psi/GPa
- Elongation at break,
- Hardness,
- Compressive strength at yield, psi/MPa
- Glass Transition Temp. Tg(°F/°C)
- Cure properties / Pot life

#### 6.4.1 Adhesive data sheet:

- **Epoxy adhesive system**
  - *Temperature performance (up to 170°C)*
  - *Strength & Toughness*
  - *Formulated for bond lines up to ...mm*
  
- **Component Properties**
  - *Mix Ratio (by weight)*
  - *Mix Ratio (by volume)*
  - *Viscosity @ 15°C (cP)*
  - *Viscosity @ 20°C (cP)*
  - *Viscosity @ 25°C (cP)*
  - *Viscosity @ 30°C (cP)*
  - *Shelf Life (months)*
  - *Colour*
  - *Component Dens. (g/cm<sup>3</sup>)*
  - *Mixed Density (g/cm<sup>3</sup>)*
  
- **Working Properties**
  - *Initial Mixed Viscosity (cP)*
  - *Gel Time - 150g mix in water (hrs:mins)*
  - *Pot Life - 500g mix in air (hrs:mins)*
  - *Clamp Time (hrs:mins)*
  - *Sag Resistance (mm)*
  
- **Cured System Properties**
  - *T<sub>g</sub> DMTA (Peak Tan δ)(°C)*
  - *T<sub>g</sub> Ult - DMTA (°C)*
  - *T<sub>g</sub>2 - DSC (°C)*
  - *T<sub>g</sub>1 - DMTA (°C)*
  - *Cured Density (g/cm<sup>3</sup>)*
  - *Linear Shrinkage (%)*
  - *Cleavage Strength (kN)*
  - *Shear Strength on Steel (MPa)*
  - *Shear Strength Wet Retention (%)*