Fibre by fibre

A comparative study of the use of micro-Computed Tomography (μ-CT) and Scanning Electron Microscopy (SEM) on the textile fragments of the Early Iron Age sites of Oss-Vorstengraf and Uden-Slabroekse Heide (the Netherlands)

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Preface

This thesis is the indirect result of the enthusiasm of dr. Gillian Vogelsang-Eastwood of the Textile Research Centre in Leiden. During my study archaeology I came in contact with archaeological textiles through her lecture and practical. From that moment my interest in archaeological textiles had been sparked. This led eventually to this work, which you are now reading.

First of all, I want to extend my gratitude to dr. Ineke Joosten and dr. ir. Hans Huisman of the Cultural Heritage Agency for granting me the chance to carry out this research. Secondly, I would like thank Jiayi Li and the staff of the PSISCHÉ beamline (Pression Structure Imagerie par Contraste à Haute Énergie) of the synchrotron Soleil for granting permission to carry out this experiment.

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1. Introduction

1.1. The importance of archaeological textiles and their research

Textiles are an often forgotten material group in archaeology. Yet from the end of the Palaeolithic various types of basketry and twining techniques were known, and from the 'Secondary Products Revolution' onwards wool fibres were processed to make textiles (Grömer 2016, 5-6; 56). The invention of textiles gave both protection against nature as well as offering a means of displaying and highlighting gender issues, personal wealth, rank and status and group affiliation (Rahmstorf 2015, 1).
One of the main reasons why textiles are often forgotten and seldom studied is the rarity of finding textiles preserved in an archaeological context (Bender Jørgensen 1992, 42). Textiles are only preserved in very specific circumstances, among others in contact with metal corrosion, preserved by salt and in waterlogged contexts, and especially in very extreme circumstances, since preserved textile have been discovered in ice, bogs and deserts (Grömer 2016, 23-26). Even though textiles are often rare, there are still many ways to study them, as for instance by studying related objects. For example, there may be indirect traces of textiles, such as impressions on ceramics or clay, or objects related to textile production such as spindle whorls and loom weights (Grömer 2016, 30-37).
These whorls and weights are just some of the tools that are part of the complex production process of textiles and are essential for the various stages of the manufacture of textiles (Belanová Štolcová and Grömer 2010, 38). In contrast to the textiles themselves, some of the tools (e.g. loom weights and spindle whorls) needed for the production of textiles are often abundant in the archaeological record. They are found both in graves and at settlements whereby the context of the tools can give us an idea about their specific use (Grömer 2016, 36).
By studying archaeological textiles and the equipment used to produce them, we can obtain an idea what they were used for (e.g., clothing, burial shrouds, wall hangings, bags or scabbard lining) (Grömer 2016, 294-318). Furthermore we can gain information about social processes involved in the production process of textiles, such as the agency of production (Good 2001, 211; Grömer 2016, 243-251), use and exchange (Grömer 2016, 256-261; Good 2001, 211) and social identity (Grömer 2016, 262-288; Good 2001, 210).

In addition, the study of textiles can give us information about the technological development of people in the past. The process of producing textiles is highly complex and requires specialised knowledge or know-how. An example of this is a simple loom. This point applies even more for the multiple heddle loom, which is needed to create a twill weave, which was already common in the Iron Age (Grömer 2016, 130-245).

1.2. Problems and new developments in archaeological textile research

During the last few decades the research of archaeological textiles has consisted mainly of descriptive studies with a focus on the production process of textiles, partly due to the limits of available research methods.

The raw fibre used in textiles is often identified with the help of light microscopy. The identification of fibres mineralised with metal corrosion is still often problematic, with only a dark mass with very little detail visible (Grömer 2016, 40). In recent years, and with advancing techniques, the use of scientific techniques has become more and more common. The use of Scanning Electron Microscopy (SEM) has become a generally applied method to determine the identity of the raw fibre and the degree of preservation of the textile. This is possible by the capacity of SEM for a higher magnification and a greater depth of view compared to conventional light microscopy (Grömer 2016, 40; Fischer 2010, 96).

In this thesis I will describe the use of SEM in comparison to the use of an even more advanced technique, named Micro Computed Tomography, or in short µ-CT, in the study of archaeological textiles. The use of µ-CT is relatively new in the heritage field, but has proven to be useful with fragile materials that have been in contact with metallic substances, for example papyrus rolls inscribed with iron-gall ink (Baumann *et al.* 2008, 1).

1.3. Why Oss-Vorstengraf and Uden-Slabroekse Heide?

The close to each other situated sites of Oss-Vorstengraf and Uden-Slabroekse Heide belong to the few prehistoric sites in the Netherlands that have yielded well preserved textile fragments. They have been preserved by mineralisation due to contact with metal. The textile fragments of Oss-Vorstengraf were preserved by their contact with bronze and iron objects including a sword and a drinking vessel. The fragments of Uden-Slabroekse Heide have been mineralised due to contact with bronze bracelets and ankle bands. Furthermore there is substantial information about the context of the burials, which have been dated to the Early Iron Age (Van der Vaart in Grömer 2015, 3-17). These burials differ from other burials. The burial of Uden-Slabroekse Heide is an inhumation burial, where cremation is the norm, while the burial of Oss-Vorstengraf is a princely grave, characterised by the imported *situla* and Mindelheim-type sword. The *situla* has been imported from the Hallstatt region, which suggests a link with the Hallstatt cultural region (Roymans 1991, 36-37; Van der Vaart 2011, 92).

The textile fragments of Oss-Vorstengraf and Uden-Slabroekse Heide have been selected for this research because of their comparable preservation and context.

1.4. The research objective of the thesis

Firstly, the objective of this thesis is to find out whether using Micro Computed Tomography (µ-CT) has an added value over Scanning Electron Microscopy (SEM) when studying archaeological textiles. By using both these techniques on the textile fragments from Oss-Vorstengraf and Slabroekse Heide I will also try to re-evaluate the archaeological value of these textiles. I will try to see whether µ-CT scans and SEM imaging can give new information about the textile fragments and what the possibly new information can mean for the archaeological value of the textiles in their archaeological context.

Due to the limitations of a bachelor thesis and the time we were able to make use of the synchrotron facility, only two samples could be analysed, one from Oss-Vorstengraf and one from Uden-Slabroekse Heide.

1.5. Research aims and questions

The research goal is:

> What is the added value of using µ-CT scans over the use of SEM in the study of archaeological textiles?

I try to reach these aforementioned research goal by answering the following sub questions:

Concerning the archaeological context:

- What is the context of the burials of Oss-Vorstengraf and Uden-Slabroekse Heide?
- In what way do the burials of Oss-Vorstengraf and Uden-Slabroekse Heide differ from the burials around them?

Concerning the scientific techniques:

- What is the added value of using µ-CT scanning in the study of archaeological textiles and do the results of creating them outweigh the costs and efforts to create them?
- What are the results of the µ-CT scans?
- What are the results of the SEM images?
- Are the µ-CT scans more informative than the more often used SEM images?

Concerning the archaeological relevance:

- What can this research add to our interpretation of the textiles and what could this mean for our interpretation of the sites?
- Can the applied techniques provide information about how Oss-Vorstengraf and Uden-Slabroekse Heide could fit into the Hallstatt cultural network?

1.6. Thesis outline

In the second chapter of this thesis, an overview is given to provide the background information for this thesis. The background of the material studied in this research, is given in chapter three. The fourth chapter addresses the techniques used in this research, on what principles they are based and how these techniques were applied in this research. In chapter five the results of both techniques used in this research are given. The results of both techniques are discussed and analysed in chapter six. The thesis in concluded in chapter seven, after which suggestions for further research are given in chapter eight.

2. Textiles in an archaeological perspective

People have been producing woven textiles since the Neolithic. With the introduction of agriculture and a sedentary lifestyle, woven textiles and textile production became more and more common. But how do we define as a textile?
The definition of what is classified as a textile is often debated. The term ‘textile’ often applied to woven fabrics in particular. However prehistoric and ethnographic research the term ‘textile’ encompasses not only woven fabrics, but all objects based on interconnected basic components (Grömer 2016, 32).

2.1. The production process of textiles

Textiles in the form of clothing are able to shelter us from the elements and provide us with the warmth we need (Good 2001, 209). Clothing also provides a means of displaying and highlighting gender issues, personal wealth, rank, status and group affiliation (Rahmstorf 2015, 1).
To manufacture textiles one has to go through a complex process requiring many tools and resources which are essential for the various stages of the manufacture of the textiles, such as is shown in figure 1 (Belanová Štolcová and Grömer 2010, 38). Furthermore, the production of textiles requires storage space, work spaces and specialised knowledge. Thus, space is needed where the raw fibre can be cultivated or where sheep can be bred, but also space is needed for the loom and for the processing and storage of the raw fibres within the settlement (Belanová Štolcová and Grömer 2010, 38; Grömer 2016, 37).

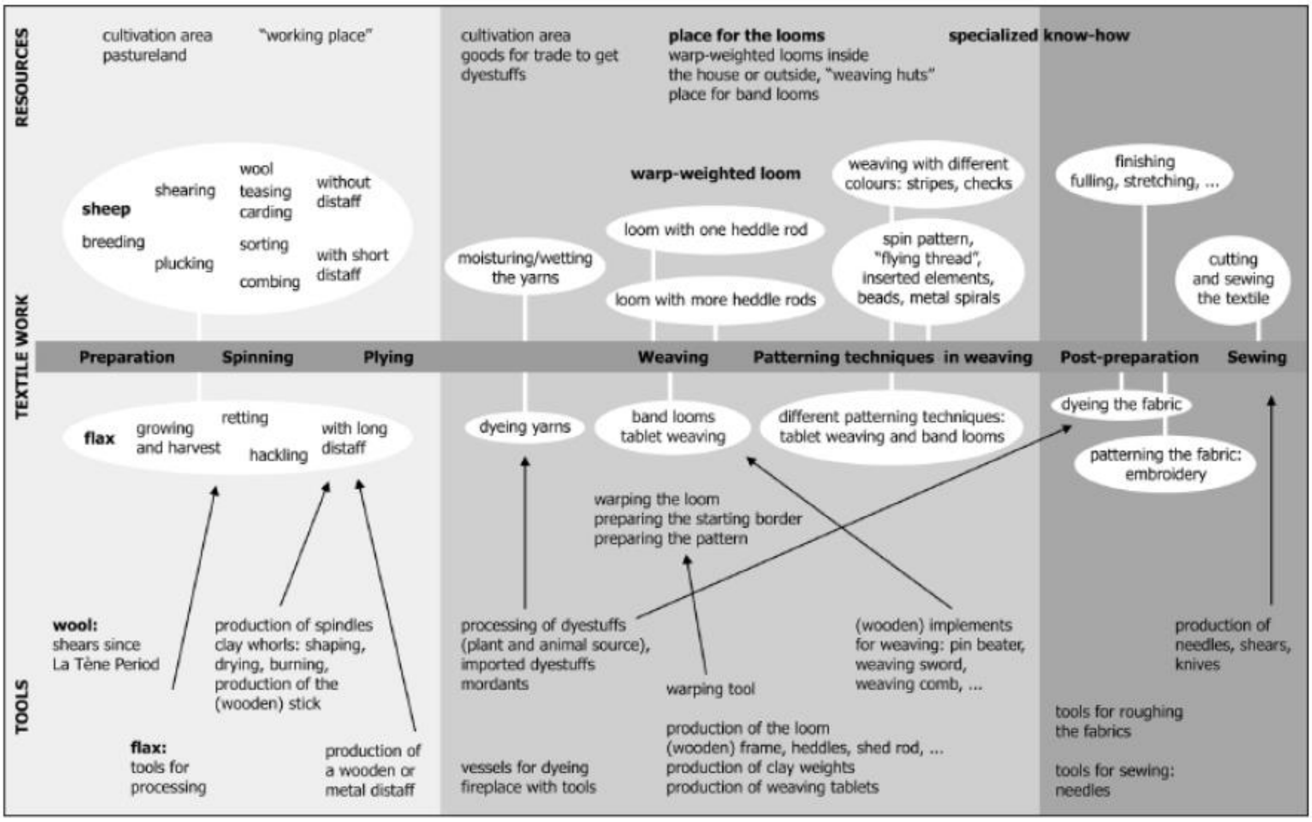


Figure 1 The production process of textiles (Grömer 2010, 38)

Raw material

The first step of the production process of textiles consists of gathering the raw material. The raw material may be plant fibres, such as flax and hemp, or animal fibres, such as wool and silk.

Plant fibres have been used to create mats and nets from the Palaeolithic and Mesolithic with the help of braiding, netting and twining techniques. The most commonly used plant fibre is flax (*Linum usitatissimum*). Flax produces seeds of which oil can be extracted, while the stem can be processed to fibres. When archaeobotanical evidence of flax is found in an archaeological context it can often not immediately be determined if the primary use of the flax was for oil or for fibres (Grömer 2016, 42-44).

Of the animal fibres, wool, the fleece of sheep, is one of the most commonly used in the production of textiles. Sheep were introduced to Europe during the Neolithic period after they had been domesticated in the Near East. Sheep can be used for meat, milk, wool and leather. The primary purpose of sheep within a settlement can be determined by studying the skeletal material. If the animals were slaughtered at a young age, it is likely that the sheep were kept for meat (Grömer 2016, 55).

The raw fibre used in the textile is the main factor that influences the properties of the end product (Andersson 2010, 28). For example, linen, the end product of flax, has an excellent ability to absorb moisture but is highly inflammable. Contrary to linen products, woollen products have excellent insulating qualities and a better resistance to fire (Harris 2010, 157-158).

Preparation of the fibres

The next step consists of preparing the fibres in a way that they can be spun. This step is a very important step, since the preparatory treatment is a significant factor in the quality of the final product (Grömer 2016, 62).

Primitive sheep breeds naturally shed their hair on a seasonal basis. The wool can be plucked and can directly be twisted to create threads. By processing the wool before it is spun the quality of the resulting threads can be improved. This can simply be done by washing the wool to remove dirt and excess of wool wax (lanolin), since cleaner wool results in more even spun threads without inclusion, such as pieces of straw. By sorting the fibres the quality of the wool can be further increased. The sorting of the fibres can be done by hand or by carding the wool.

The two basic methods of preparing the wool are carding and combing. Both techniques aim to remove dirt and align the fibres to make spinning easer, which will result in more uniform threads (Grömer 2016, 66-67). Thread spun from carded wool is called woollen thread and the thread spun from combed wool, is called worsted thread. Worsted thread is spun from parallel fibres of good quality wool (wool mostly consisting of fine hairs of the undercoat of the sheep) after a long process of combing the wool. This results in a smooth and uniform thread which is also water repellent. Carded thread is more coarse in appearance with protruding fibres. This is more elastic, absorbs more moisture and is warmer. Because of the protruding fibres it is also easier to felt. Felting consist of processing the wool by mechanical means, such as trampling, to make the fibres cluster together, which is easier with protruding fibres. When this process is done to a woven textile, it is called fulling, and results in a warmer and softer textile.

The appearance of both threads are quite different, with the worsted thread being smooth, shiny and firm and the woollen thread being soft and fluffy (Grömer 2016, 70).

In the archaeological rarely tools associated with the process of fibre preparation have been found, because sometimes these tools have perished since they were made of organic material (Grömer 2016, 72).

Spinning

To produce a thread from woollen fibres, the fibres have to be spun. Spinning can be done without the help of any implement by simply twisting the fibres by hand into a thread. By using an implement such as a drop spindle, the spinning process can be quickened. A drop spindle consists of a wooden rod with a length of 20-30 centimetres with a weight, the spindle whorl, placed along the lower third. By turning the spindle, fibres can be twisted into thread. By turning the spindle clockwise or counter clockwise, respectively right-twisted (z-spun) or left-twisted (s-spun) thread is created (fig. 2) (Grömer 2016, 75). How tightly the thread is spun can be studied by the angle of the twist, with a tight spun resulting in a hard thread and with a loose spun resulting in a soft thread (Walton and Eastwood 1984, 11). Additionally, tightly twisted thread is stable and is thus often used for the warp threads (the vertically running threads on the loom) and for tablet weaving, while loosely twisted threads make up a good weft (the horizontal running threads on the loom) for absorbent and warm textiles (Grömer 2016, 91).

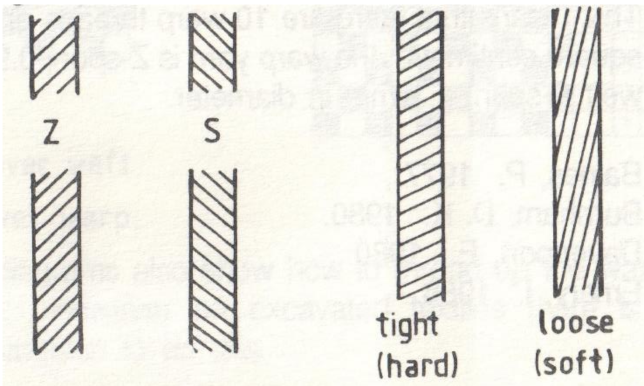


Figure 2 The way threads can be spun (after Walton and Eastwood 1984, 11)

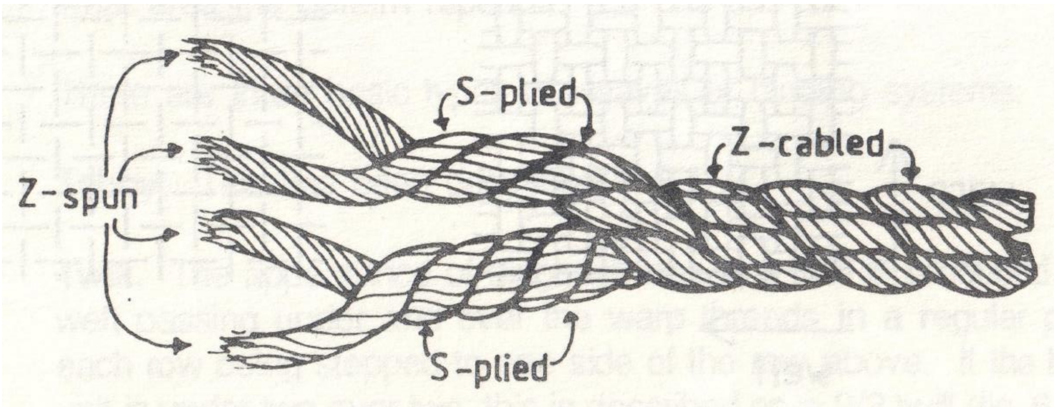


Figure 3 The way threads can be plied (after Walton and Eastwood 1984, 12)

Two or more separate threads can also be plied (the twisting together of previously spun threads) to create a stronger and more durable plied thread (fig. 3). To create plied thread the previously spun threads are twisted in the opposite direction of the twisting direction of the single threads (Grömer 2016, 80; Walton and Eastwood 1984, 11-12).

Since organic material is often not preserved, the only objects sometimes found in an archaeological context related to spinning are spindle whorls. The spindle whorls were often made of fired clay or in some instances made of stone or bone. Spindle whorls were sometimes lost in settlement contexts or given as grave goods in both cremation and inhumation burials.

Weaving

The next step of the production process consists of weaving the threads into a textile. This can be done by interlacing threads under and over each other. The simplest of these weaves is the tabby weave. Every weave consists of a starting border, a selvedge, a warp and a weft (fig. 4).

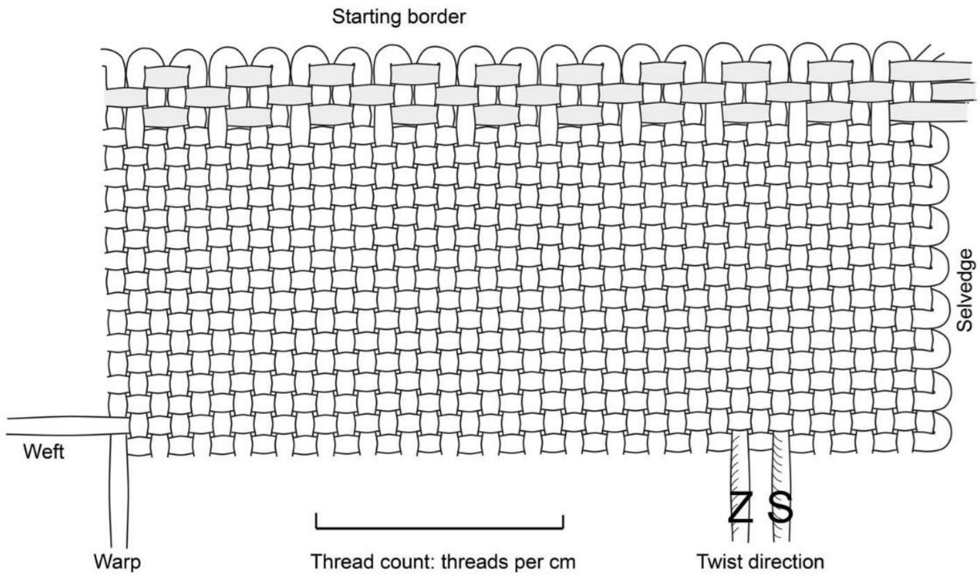


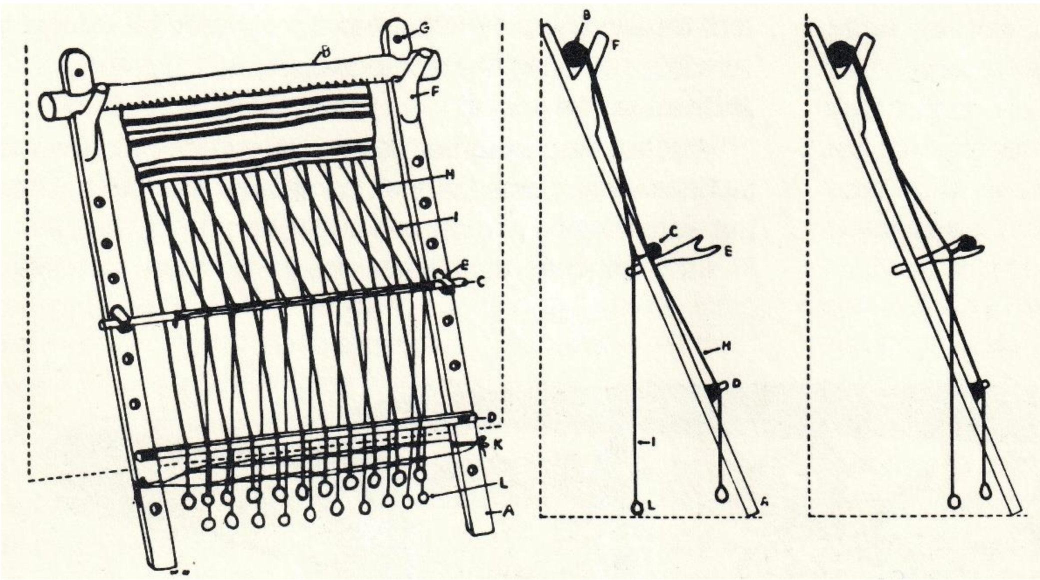
Figure 4 Technical details of textile analysis (after Grömer 2015, 2)

The starting border is the top edge of the textile where the warp turns back. The starting border is often woven in a special manner, in order to strengthen the upper edge of the textile (Walton and Eastwood 1984, 19; Grömer 2016, 118). By making use of a starting border the threads of the warp are sorted and are spaced regularly. Furthermore a starting border both strengthens and decorates the edge of the fabric (Grömer 2016, 118).

The selvedges are the sides of the textile. These are the places were the weft turns back on itself (Walton and Eastwood 1984, 19; Grömer 2016, 122).

The warp is the system of threads which runs vertically on the loom. Through the warp threads the weft is woven, which is the system of threads that runs horizontally (Walton and Eastwood 1984, 4).

Without the aid of a loom, every individual thread has to be moved under and over each individual thread of the warp by hand. To quicken the weaving process a loom can be used. A basic warp-weighted loom, is shown in figure 5. The added value of using a loom when weaving is that a whole series of threads can be moved simultaneously by moving the heddle rod. As the name of the loom suggests the warp of the fabric is weighted. By attaching loom weights to bundles of the warps threads, the warp is held under tension by the weight of the loom weights.



A Upright
B Beam
C Heddle rod
D Shed rod
E Supports for heddle rod
F Crotches for holding beam
H Front warp threads
I Back warp threads
K Chained Spacing cord
L Loom weights

Figure 5 The components of a warp-weighted loom (after Broudy 1979, 24)

Since a warp-weighted loom is used vertically, it often rests against a wall and thus will not take up much space (Grömer 2016, 107).

Common weaves

The main properties of a textile are determined by the raw material used. The properties of the textile can further be influenced by the weaving process. By changing in the standard one-over-one-under pattern (the tabby weave) it is possible to slightly change the properties and the look of the resulting textile. With a warp-weighted loom it is easy to create different weave patterns. A tabby weave is the most plain weave there is, consisting of one-over-one-under pattern. To create more complicated weave patterns, multiple heddle rods are needed. To create a simple twill weave at least three heddle rods are needed (Grömer 2016, 131). Twill weaves, and other more complex patterns, are more difficult to create, but give an attractive pattern to the textile and slightly alter the properties of the textile. For example, a twill weave has an increased thermal efficiency, since multiple threads lie on top of each other. Furthermore the textile is more elastic than a tabby weave.

The most commonly found weaves in archaeological contexts are the tabby and the twill weave. Both of these weaves have many variations, which all have a specific effect on the resulting textile. Tabby weaves have been known since the Neolithic, with the tabby weave being the bulk of the weaves found from the Neolithic until the Middle Bronze Age. During the Hallstatt period twill weaves were preferred over tabby weaves, while during the Late Iron Age the tabby weave was again more common (Grömer 2016, 129). In figure 6 the specific pattern of the most common weaves used is shown (Grömer 2016, 137).

Optional steps: Dyeing and fulling

The production process of textiles also has some optional steps. Examples of these optional steps are dyeing and felting.

- Dyeing

Throughout history mankind has had an affinity with colours (Brunello 1973, 16). A wide range of plants give a wide variety of colours, which can be used as dyestuffs. In the Bronze age woad, bedstraw, luteolin and tannin based dyes were already in use. During the Iron Age the colour palette was extended with madder, scale insects, Tyrian purple and orchil for red colours and buckthorn and saffron for yellow colours (Grömer 2016, 167). Some less potent dyes needed to be fixated to increase the colourfastness. These dyes need the help of a mordant, a dye fixative. Mordants, such as various metal salts (e.g. copper and iron) and tannins, cannot only fixate a dye, some can be used to change to resulting colour (Grömer 2016, 142).

- Fulling versus felting

The fulling process consist of processing the wet cloth with mechanical means, such as trampling, to make the textile warmer and to release the dirt and lanolin. Felting consists of the same process, but is done with fibres instead of a finished cloth (Wild 1998, 57).

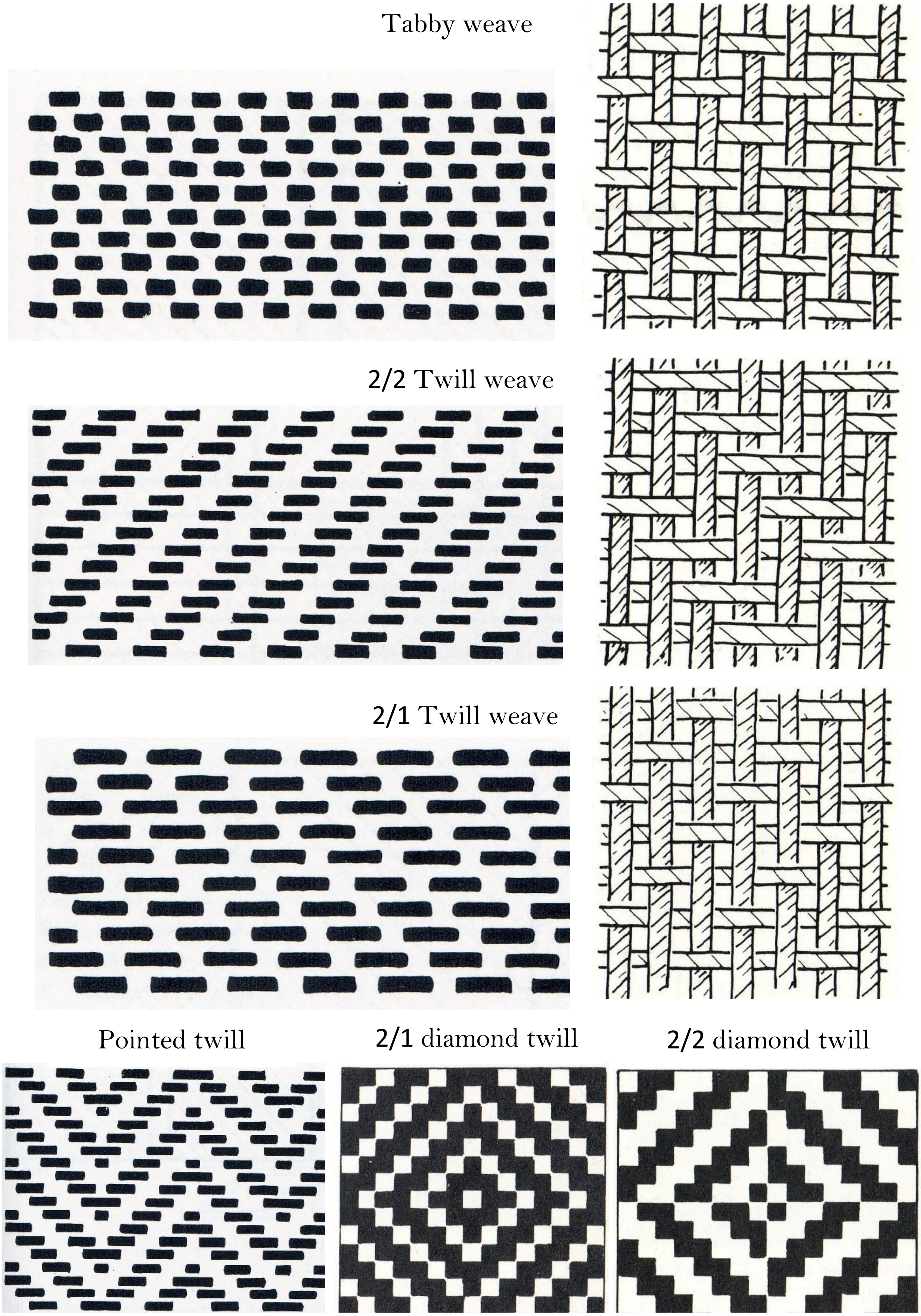


Figure 6 Overview weave types mentioned in this thesis (after Hald ,148-149; Wild 1988, 42-43)

2.2. The study of archaeological textiles

As mentioned earlier, the study of archaeological textiles is often difficult, because of scarce preservation of the material. Still, when textiles are preserved, there are many methods to receive information. By studying the technical details of a textile, in combination with archaeological data, we can obtain information about how the textiles are used to express identity, including gender, age, family affiliation, social status, occupation, religion and ethnicity. Thus, the study of textiles can help our understanding of human affairs (Andersson Strand *et al.* 2010, 150).
In the next paragraphs I will give an overview of the most common methods used by textile specialists.

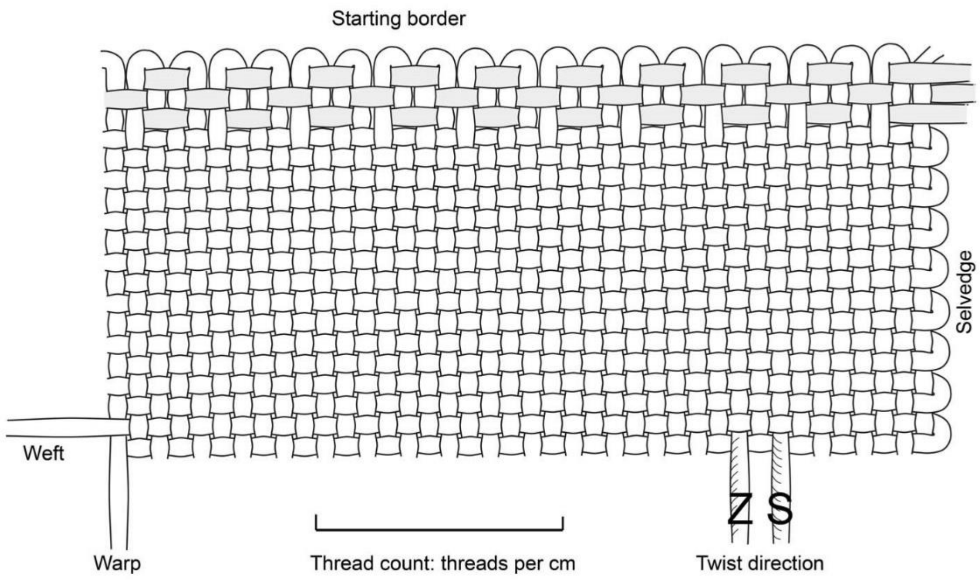


Figure 7 Technical details of textile analysis (after Grömer 2015, 2)

2.2.1. Basic analysis of textiles

The basic analysis of a textile can be carried out by the naked eye in combination with optical microscopy. During the basic analysis, various descriptive features of the textile are described, with the most important features being: dimensions, condition, colour, textile structure, thread structure, fibre, decoration, irregularities and faults, wear through use and construction (Andersson Strand *et al.* 2010, 153; Walton and Eastwood 1984, 1-33).

Dimensions

With dimensions both the overall dimensions and the dimensions of specific structural elements are meant. The dimensions indicate how much of the textile has been preserved and can sometimes give information about the use and function of the textile.

Condition

With the condition of the textile, both the state of the textile in which it has been preserved (organic, mineralised or carbonised) and the degree of preservation are meant. The condition of the textile influences both the amount of information that can be retrieved, the type of analyses that can be performed and a possible conservation strategy.

Colour

The colour of the textile can indicate the natural pigmentation and/or the presence of dyestuffs. The colour of the textile can be an indication of the available resources and technologies at that time and how colour was used for both aesthetic and functional purposes.

Textile structure

The textile structure includes the weave type, the thread count and types of edges (fig. 7). These give an idea of the weave technique used and its intended purpose.

Thread structure

The thread structure includes the twist direction, the angle and the thickness of the threads used in the textile. These aspects determine the spinning technique used and the intended purpose of the thread.

Fibre

The fibre used in the textile can give information about the local availability of resources or can give an indication of the exchange of fibre material. The selection and preparation of the raw fibres influence both the properties of the finished product, as well as possible use.

Decoration

The presence of decoration, such as woven patterns, embroidery and appliqués, can give an idea about the function and/or the meaning of the textile.

Irregularities and faults

The irregularities and faults in a textile give us an idea about the people who produce the textile, their skill or the number of weavers that worked on the textile. Furthermore it gives information about the technology and provides evidence for the construction technique of the textile and possibly the type of loom used for its production.

Wear through use and repairs

The presence of use-wear and/or repairs gives information about the degree and duration of use, reuse and possibly about the value of the textiles.

Construction

With the construction of the textile its tailoring is meant. When the textile is used for clothing, the textile can give an indication of both the gender and age of the user and in some cases the user's role in society.

2.2.2. Specialised methods

The aforementioned methods are just the basic analyses of a textile. With the use of scientific techniques becoming generally applied in the research of archaeological artefacts. New ways of retrieving new types of information from archaeological material have become available (Fischer 2010, 96). Examples of these techniques are isotopic tracing to determine geographical provenance, High Performance Liquid Chromatography (HPLC) for dye stuff analysis, DNA analysis to determine the animal species and Scanning Electron Microscopy (SEM) to determine the raw fibre used in the textile (Andersson Strand *et al.* 2010, 154).

Fibre analysis

The investigation of the fibre used in a textile can help our understanding of selective breeding/cultivation, the selection and processing of fibres and their wear (Andersson Strand 2010, 154).
In some cases the raw fibre used in a textile can be identified with optical microscopy. Still with very degraded textile remains and mineralised textiles it is often not possible to achieve a sufficient identification of the raw fibre. In these instances Scanning Electron Microscopy (SEM) can be used. SEM can also be used to assess the degree of preservation of a textile. How SEM exactly works is discussed in chapter four.

Dye analysis

When a textile is found in an archaeological context it is often brown or black, with its original colour often lost. If it is suspected that an archaeological textile might have been dyed, the dyestuff that was used can be determined with the help of various methods, including SEM-EDX and HPLC-PDA analysis. HPLC-PDA stands for High Performance Liquid Chromatography with photo diode array detection. The resulting spectrum of the analysis are then compared with the reference collection to determine the origin of the dyestuff (Grömer 2016, 144-147).

When SEM is paired with a EDX detector a chemical analysis can be carried out. This chemical analysis can help determine which elements have caused the mineralisation of the textiles and, if there is a dye present, which mordant has been used to improve the colourfastness of the dyestuff (Jones *et al.* 2007, 248).

3. The textile fragments of the sites of Oss-Vorstengraf and Uden-Slabroekse Heide

The textile fragments used in this research come from the archaeological sites of Uden-Slabroekse Heide and Oss-Vorstengraf (The Netherlands). Both sites are located in the province of Noord-Brabant in the southern part of the Netherlands (fig. 8). The site of Oss-Vorstengraf is known for being one of the richest prehistoric burials in the Netherlands. The mound of Oss-Vorstengraf is also one of the largest barrows in northwest Europe, with a diameter of 53 meter (Van der Vaart in Grömer 2015, 3).
The site of Uden-Slabroekse Heide consists of a large urnfield near Uden. The urnfield mainly dates to the Early Iron Age. In this research special focus will be given to a grave from the northern part of the urnfield, since this grave has brought forth multiple textile fragments (Van der Vaart in Grömer 2015, 17).

Figure 8 The location of Oss-Vorstengraf and Uden-Slabroekse Heide (figure by author)

3.1. The site of Oss-Vorstengraf

Research history of Oss-Vorstengraf

In 1933 an area south of Oss was levelled by reclamation of the heath to accommodate a group of gypsies. Since multiple urns had been found here, the town secretary had arranged that someone with archaeological experience would oversee the reclamation. Under his supervision a bronze vessel was found. The National Museum of Antiquities in Leiden was notified and the next day the bronze vessel was 'excavated' under supervision of dr. Bursch. He covered the vessel in plaster and took it to Leiden to be excavated in a laboratory. The same year Bursch excavated what was left of the mound (Fokkens *et al*. 2012, 183).

In the years after the discovery of the princely grave and the surrounding gravemounds, the terrain was in use as a car graveyard and an extended part of an caravan camp. During the removal of both in the 1970s, the municipality of Oss came to the conclusion that intensive sanitation of the ground was needed. The process gave the possibility to restudy the princely grave of Oss (which location was only approximately known) and to better understand the wider context of the grave mounds surrounding the princely grave of Oss. During archaeological research in the period 1997-2005 the precise location of the princely grave was rediscovered (Jansen *et al.* 2007, 34).

It was discovered that the princely grave dates to the Hallstatt C period, and was superimposed upon an older Bronze age mound with a diameter of 16 meters. The younger mound was likely placed upon the older mound to create a mythical ancestry with the person buried underneath the older mound, possibly to strengthen their own importance. This practice also made the younger mound look bigger (Fokkens *et al.* 2012, 192).

Archaeological background of the site Oss-Vorstengraf

The burial mound of Oss-Vorstengraf is not an isolated archaeological feature. It is part of a greater ancestral landscape, which was deliberately kept open by grazing or burning. About 450 meter to the east the site of Oss-Zevenbergen is located. In this barrow group two mounds were discovered that have been categorised as *Vorstengraven*, based on the size of the mounds and presence of sword fragments (Fokkens *et al.* 2012, 192).

*Figure 9 The best known finds of Oss-Vorstengraf (*Fokkens *et al.* 2012, 199; © Museum of Antiquities)

The finds of Oss-Vorstengraf

The bronze drinking vessel, called a *situla*, contained many finds, of which the most prominent an iron sword with a gold-inlayed handle, which is of the Mindelheim-type. The finds that are part of the permanent exhibition in the Dutch National Museum of Antiquities are shown in figure 9. The bronze *situla c*ontained an iron Mindelheim-type sword, two iron horse-bits, bronze bridle decorations, bronze yoke rosettes and iron yoke toggles, an iron axe and knife, two iron razors, three bronze and iron clothing pins and a number of fragmented antler and bone objects (Van der Vaart in Grömer 2015, 13). A significant part of the grave goods of Oss-Vorstengraf is not part of the permanent exhibition and are in stored in the repository. These finds include a fragment of an iron ring, multiple lead and tin fragments, several pieces of leather and a decent amount of textile fragments (Fokkens *et al.* 2012, 199-200). It is theorized that most of the textiles were used as packing material for the various finds in the bronze *situla* (Fokkents *et al.* 2012, 200-201).

It is likely that both the Mindelheim-type sword and the bronze vessel of Oss-Vorstengraf have been imported from the Hallstatt region, which covered a significant part of central and western Europe. The presence of horse gear/wagon remains in combination with swords of the Mindelheim type is characteristic for the Hallstatt C period burials. Even more, iron swords of the Mindelheim type are considered to be produced in southern Germany (Roymans 1991, 36-37; Van der Vaart 2011, 92). The type of bronze vessel used as an urn in Oss-Vorstengraf has been found throughout the Hallstatt region. It is theorised that this type of vessel would have been produced in the Alpine region (Roymans 1991, 37-39; Van der Vaart 2011, 46).

The use of imported and exotic goods in the burial might have been a way to strengthen the deceased’s position. It also gives the deceased a way to legitimise his, and his descendants, power. This claim to power is even more strengthened and legitimised by locating the mound near an ancestral burial place, which gives the ability to claim a mythical ancestry.

Interestingly, while the goods were imported from the Hallstatt region, the manner in which they were incorporated in the grave is completely different to the manner practiced in the Hallstatt core area, mainly central Europe. Through the local interpretation the initial meaning of the imported objects was apparently reshaped and transformed (Fokkens *et al.* 2012, 200-202).

The textile fragments of Oss-Vorstengraf

Most of the textile fragments have been stored in a box, shown in figure 10, in the Dutch National Museum of the Antiquities (Rijksmuseum van Oudheden). During a restoration attempt in 1993 some of the fragments were treated with paraloid, though it is unclear precisely which fragments were treated (Kempens and Lupak 1993, 53-54).

Figure 10 The box with the textile fragments of Oss-Vorstengraf (© Museum of Antiquities)

In recent years the textile fragments of Oss-Vorstengraf have been studied by Lise Bender Jørgensen and Karina Grömer.
Bender Jørgensen studied the textiles in 1992 and identified four different cloth types (Bender Jørgensen 1992, 218). The different cloth types are described in table 1.

Table 1 Cloth types of Oss-Vorstengraf identified by Bender Jørgensen (after Jørgensen 1992, 218)

Cloth type	Weave	Details	Comments
Textile 1	Diamond twill with point repeat in one system, displacement in the second	Spin z/s, count 25/20 threads/cm, repeat 24/?	-
Textile 2	Diamond twill with point repeat/displacement	spin z/s, count 22/21 threads/cm	-
Textile 3	Tabby	Spin Sz/Sz, count 7/5 threads/cm	Found on sword
Textile 4	Probably tabby	Spin z/s, count 12/7 threads/cm	Found on iron knife

Recently, in 2015, the textile fragments were studied by Karina Grömer. Grömer identified eight different cloth types of the textile fragments from Oss-Vorstengraf, which she named A to H. In table 2 her findings are summarised.
It is evident that the analysis of archaeological textiles has made major advances in the last twenty-five years. Grömer identified eight different weave types, where Bender Jørgensen identified four. This can be attributed to the advancement of techniques used to analyse the textiles, including optical microscopy and SEM (Grömer 2015, 1-20).

Dye stuff analysis of the textiles of Oss-Vorstengraf

In 2016 a dye stuff analysis of the different weaves of Oss-Vorstengraf was carried out by Van Bommel and Joosten (Joosten 2016, 1-11). The dyestuff analysis consisted of UHLPC-PDA and SEM-EDX. During the investigation no traces of dyestuffs or mordants could be identified on the various samples tested. This led to the conclusion that either the textiles were not dyed in the first place or that the dyes are degraded (Joosten 2016, 7-8).

Table 2 Analysis of the textiles of Oss-Vorstengraf identified by Grömer (Grömer 2015, 3-16)

Cloth type	Weave	Context	Colour and material	Thread system 1	Thread system 2	Remarks	Interpretation
Textile A	Coarser tabby	On sword handle (7.3-1), rings (7.10j-1), iron ring (7.101), box (7.19)	Rust-red/blackish, wool with kemp	0.5 mm z-thread, 5-6 threads per cm	0.4-0.5 mm s-thread, c. 6 threads per cm	Open weave, worn out surface, low cover factor	Warpping material?
Textile B	Medium fine tabby	Sword (7.3-2), box (7.19)	Rust-red/blackish, material too degraded to identify	0.4 mm z-thread, c. 15 threads per cm	0.4 mm z-thread, 14-15 threads per cm	Dense fabric	Warpped around the sword?
Textile C	Fine diamond twill	Sword (7.3-2), box (7.19)	Rust-red/black to reddish-brown, wool	0.2 mm s-thread, c. 20-24 (20-22) threads per cm	0.2 mm z-thread, c. 20-24 (24-26) threads per cm	Point repeat in one direction, displacement in other	Found covering textile D, grave good in its own right
Textile D	Finer tabby	Sword (7.3-2), box (7.19)	Rust-red to dark brownish, wool	0.3-.04 mm s-thread, 16 threads per cm	0.3-0.4 mm z-thread, 16 threads per cm	Open weave	Textile folded into textile C, grave good in its own right
Textile E	Fine diamond twill	Rings (7.10j-2), box (7.19)	Rust-red/blackish, bast fibre?	0.3 mm s-thread, c. 20 threads per cm	0.3-0.4 mm z-thread, c. 10 threads per cm	Folded textile, high quality object diamond twill with point repeat	-
Textile F	Coarse tabby	Iron knife (7.9)	Rust-red, no fibre identification	0.6 mm s-thread, 12 threads per cm	0.6 mm z-thread, 12 threads per cm	Very dense, slightly ribbed appearance	Lining of leather knife sheath or warpping of knife blade
Textile G	Coarse twill	Box 7.19	Rust-red/blackish, wool	0.4 mm z-thread, 5-7 threads per cm	0.4-0.5 mm s-thread, c. 6 threads per cm	Threads low twist, some fragments severely worn, use-wear?	Unclear, only found in box
Textile H	Repp	Box 7.19	Rust-red/blackish, wool?	0.8 mm zS-plied thread, threads per cm not countable	0.3-0.4 mm z-thread, threads per cm not countable	No selvedge survided, possibly a repp band	-

The sample Oss-G

The sample selected from the site Oss-Vorstengraf for the analysis was sample Oss-G (fig. 11). This sample was selected based on its size, since subsampling was not needed. The dimensions of the sample are circa 10x10x2 millimetre. The weave of the sample consists of a coarse twill, as identified by Grömer (Grömer 2015, 14).

Figure 11 Sample Oss-G (© Museum of Antiquities)

3.2. *The site of Uden-Slabroekse Heide*

Research history of Uden-Slabroekse Heide

The first archaeological research of the site was carried out in 1923 under supervision of A.E. Remouchamps of the National Museum of Antiquities in Leiden. During this research, multiple burial mounds were (partially) excavated. After the excavation by Remouchamps, the terrain was levelled and taken in use for agriculture. The terrain retained this function until it was acquired by Staatsbosbeheer to be redesignated as a nature reserve in 2003. Before this archaeological research was carried out by Archol and the Faculty of Archaeology of Leiden University in 2005, to make an inventory of present archaeological remains. In 2010 the investigation of the site was continued with an extensive excavation of the cemetery (Van Wijk and Jansen 2010, 7).

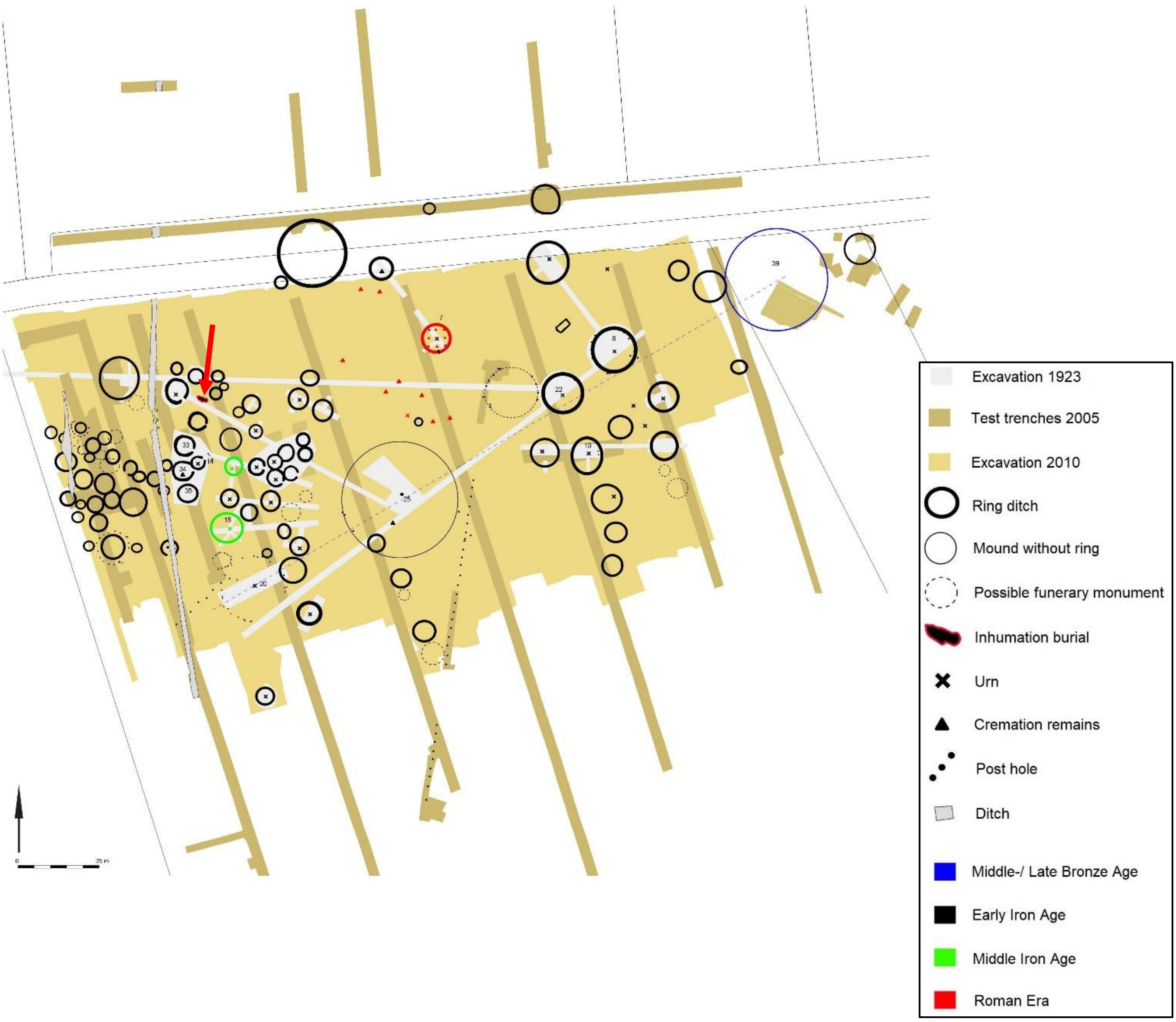


Figure 12 Overview excavations of Uden-Slabroekse Heide, red arrow indicates the inhumation grave (after Jansen in press.)

Archaeological background of the site Uden-Slabroekse Heide

The site of Uden-Slabroekse Heide consist of a cemetery with 64 funerary monuments, of which 39 have been researched (fig. 12). The cemetery dates most likely to the Early Iron Age, based on the significant number of discontinuous ring ditches and the absence of elongated and square features, which are respectively characteristic for the Late Bronze Age and the Middle Iron Age. Another source used to date the cemetery and the individual burial mounds are the urns containing the cremation remains (Jansen and Van Wijk 2010, 77-78). While the Early Iron Age remains the main period of use, the overall period of use spans from 1800 BCE until 200 CE, though the use will have been discontinuous. It Is likely that near the Bronze Age burial mounds during the Iron Age an urnfield was constructed, possibly to create an ancestry with the older burial mounds (Jansen and Van Wijk 2010, 83-84). All of the burial mounds were surrounded with a ring ditch. Since there were almost no overcutting features found, which would mean that during the time the burial ground was in use all burial mounds were visible above ground (Jansen and Van Wijk 2010, 75).

The inhumation grave of Slabroekse Heide

In an open area surrounded by several ring ditches an inhumation grave was found, which differs the other burial which are cremations. There was no evidence supporting a possible barrow covering the grave, thus it was theorised it is a so-called flat grave. Still the lack of overcutting suggests that the grave was marked above ground. The grave consisted of a deep pit of a depth of circa 1.5-2 metre supported with oaken planks to create some sort of a small burial chamber of 3 by 1.10 metre. Oaken blocks were placed at the head and feet of the deceased. All of the planks and blocks were charred in a controlled and probably deliberate manner, which would have required a large fire. The top half of the burial pit was filled with partially burned oaken branches, possibly the remains of the fire used to burn the planks and blocks (Van der Vaart in Grömer 2015, 17).

The finds of the inhumation grave of Slabroekse Heide

In the inhumation grave a shadow of a corpse was found measuring about 1.60 meter. Any skeletal remains had completely dissolved which made it impossible to determine the sex of the deceased. The deceased was buried with multiple bracelets and anklets (fig. 13). The bracelets on the left wrist showed heavy use-wear where they touched, which indicates they were worn together for a long time. The other gift consisted of an iron pin with twisted decoration and a small bronze ring next to the right arm. Next to the left shoulder a toilet set was found consisting of an iron nail cutter with twisted decoration and tweezers with still a piece of leather knotted to it. The toilet set was accompanied by an amber bead. The bead showed use-wear traces that is was used to close something, possibly a pouch. Beneath the pouch a fragmentary pin was found. The distribution of the fragments indicates that the pin was deliberately broken prior the placement in the grave. Lastly, metal spiralled rings were found, which were likely worn in the hair. On both the bracelets, anklets and bronze pin, textile fragments were found (Van der Vaart in Grömer 2015, 17).

Figure 13 The finds of the inhumation grave of Uden-Slabroekse Heide, excluding the textiles (© Restaura bv, Haelen)

The textile fragments of Slabroekse Heide

During the excavation of the site of Uden-Slabroekse Heide in 2010 various textile fragments were found in an inhumation grave. The textile fragments were preserved by their contact with bronze bracelets and anklets and the bronze pin. Due to the contact with the metal objects the textile fragments were mineralised (Grömer 2015, 17).

Figure 14 The textiles of Uden-Slabroekse Heide in situ (after © Restaura bv, Haelen)

The context of the textiles

The textile fragments and their connected metal object were recovered *en bloc* during the excavation (fig. 14). In this way they could be excavated and conserved in the restoration workshop of Restaura (Heerlen, the Netherlands). During the conservation the textile fragments were impregnated with a solution of 10% PVAc (Restauratieatelier Restaura 2011, 4-18).

The textile fragments of the inhumation grave of Uden-Slabroekse Heide have recently been studied by Joke Nienkter and Karina Grömer.

Nienkter studied five fragments (two with number 058, one with number 070, 071 and 072, respectively). Nientker identified the weaves of all fragments as a 2/2 twill weave with a displacement in order to create a herringbone pattern. The threads are z-spun and have a diameter of between 0.588 mm and 0.997 mm, with an average thread thickness of 0.8 mm. She interpreted that the textile fragments likely belong a burial shroud, but a textile fragments found on the inside of the bracelets suggest that might have been a long sleeved garment (Nientker *et al.* in press, 2).

In 2015 the textile fragments of Uden-Slabroekse Heide were studied by Karina Grömer (table 3). She came almost to the same interpretation as Nientker. Both determined the textiles have a 2/2 twill weave. Interestingly, Grömer identified two different textiles, textile A and textile B. Textile A as a coarser twill, and textile B as a finer twill. Grömer interpreted the colour checked textile A as possibly being a long-sleeved garment that reached to the ankles, while textile B might be a shroud of some sort.

Dyestuff analysis

A dyestuff analysis (HPLC-PDA) was carried out on the textiles by Maarten van Bommel. The dye stuff analysis pointed out that the textiles of find number 58, 70 and 71 would have been dyed red. The dyestuff could not be pinpointed to a specific dyestuff. The dyestuff likely originates from extracts of plants or insects and is comparable to dyes obtained from madder (*Rubia tinctorum*) or scale insects (*Coccoidea*) (Nientker *et al.* in press, 2-3).

Sample Slabroek 70A

Sample Slabroek 70A (of number 70 textile A) is the sample for the analysis we selected from the site Uden-Slabroekse Heide (fig. 15). The dimensions of this sample are circa 15x13x3 millimetre. The weave of the sample consists of a coarse twill, as identified by Grömer (Grömer 2015, 18). This textile was found on the right bracelet in 2-3 layers. It was microstratigraphically underneath the finer twill of 70-2 textile B (Grömer 2015, 18).

Figure 15 Sample Slabroek 70A (© Restaura bv, Haelen)

Table 3 Cloth types of Uden-Slabroekse Heide identified by Karina Grömer (Grömer 2015, 17-20)[1]

Context	Cloth type	Weave	Colour/material	Thread system 1	Thread system 2	Remarks
Findnumber 70 (right bracelet)	Textile A	Coarse 2/2 twill	Mostly brown, some other colours visible, wool	Single thread z spun, 30°-40°, 0.5-0.7 mm, 9 threads per cm	Single thread z spun, 30°-40°, 0.6-0.8 mm, 11 threads per cm	Surface is worn out, looks felted in- and outside; threads irregularly spun
Findnumber 70 (right bracelet)	Textile B	Finer 2/2 twill	Brownish, wool	Plied thread zS, 20°, 0.3-0.4 mm, 16-18 threads per cm	Plied thread zS, 20°, 0.3-0.4 mm, c. 16 threads per cm	Microstratigraphically over textile A
Findnumber 71 (left bracelet)	Textile A	Coarse 2/2 pointed twill	Brownish	Comparable to number 70 textile A	Comparable to number 70 textile A	Unlike number 70 point repeats visible, very degraded
Findnumber 71 (left bracelet)	Textile B	Finer 2/2 twill	Brownish	Comparable to number 70 textile B	Comparable to number 70 textile B	Covered by very degraded leather, over textile A
Findnumber 72 (anklet)	Textile A	Coarse 2/2 pointed twill; point repeat, repeat after more than 20 threads	brownish	Comparable to number 70 and 71 textile A	Comparable to number 70 and 71 textile A	Well preserved, pattern visible of dark and light threads, possibly a checked pattern of alternating dark and light threads, folded textile

[1] Grömer mentioned in her report that she failed to report the textile fragments of findnumber 58, which is why these textiles are not mentioned

4. Methodology

The first step of my research consisted of a literature study to identify the textile fragments to be used in the research. The sites of Oss-Vorstengraf and Uden-Slabroekse Heide were chosen since they are among the few prehistoric sites that have yielded preserved textiles. Furthermore both sites were dated to the Early Iron Age and have thoroughly documented context data.
The next step consisted of creating µ-CT scans of the samples from Oss-Vorstengraf and Slabroekse Heide. The samples were studied with the PSICHÉ (Pression Structure Imagerie par Contraste à Haute Énergie) beamline at the synchrotron facility SOLEIL in Saint Aubin, France. The same samples were analysed by scanning electron microscopy (SEM) at the laboratory of the Culture Heritage Agency of the Netherlands in Amsterdam. The µ-CT data from both samples were studied with the help of the program 'AVIZO' at the Faculty of Civil Engineering and Geosciences of the University of Delft in Delft. The results were compared with the SEM images from the samples to study the added value of using µ-CT scans.

In the next paragraphs an explanation of the techniques used in this research is given and how these techniques were used. The techniques used in the research are:

4.1. Micro Computed Tomography (micro-CT)

Computed Tomography, often abbreviated to CT, is a non-destructive technique used to create cross-sections of a physical object, which can be used to obtain 3D reconstructions of the object. This technique is generally applied in the medical field. For this experiment synchrotron-based micro Computed Tomography was used, since this technique can provide the needed resolution to be able to distinguish the individual threads which make up the textiles.

We were granted time within the project of '3D microstructure of exceptionally-preserved cellulosic textiles from the Ancient Near East (V-II millennium BC)'[2] in the synchrotron facility of SOLEIL and we were able to analyse one sample of Slabroekse Heide and one of Oss-Vorstengraf. We chose the samples based on their dimensions since the beam line is only able to process samples with dimensions of 10 by 10 mm[3]. The samples were selected based on their size, in which way the samples did not have to be sub-sampled. The sample selected from Slabroekse Heide is Slabroek-70A and the sample selected from Oss-Vorstengraf is Oss-G. The same samples were later studied using SEM, to be able to make a comparison between the techniques.

How does Computed Tomography work?

Any CT system uses three principal components: an X-ray source, an X-ray detector and a rotational stage (fig. 16) (Noel 2008, 1). The X-ray source emits X-ray radiation, which travels through the sample onto the detector. X-ray radiation is created when an high energy electron hits another electron out of the atom. When this happens a photon is released. Many of these photons together compose the X-ray radiation.
With medical CT systems the CT system itself turns around the sample, or in a medical case a patient. In our case with the synchrotron-based CT the CT system remained stationary and the sample turned.

The various forms of Computed Tomography

There are many forms of CT used in both the medical and the scientific field. Most commonly used are CT and micro CT. The difference between CT and micro CT is that

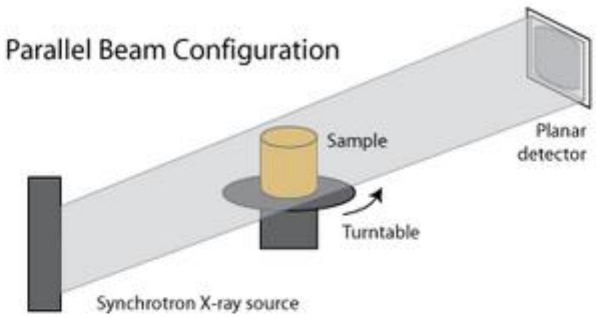


Figure 16 Setup of a Synchrotron based micro-CT (after http://serc.carleton.edu)

micro CT has to ability to capture microscopic details as small as a few micrometres. This

[2] Part of the PhD project 'Physico-chemical study of exceptionally preserved archaeological textiles in mineralized form' by Jiayi Li
[3] Pers. comm. Jiayi Li of the synchrotron facility Soleil

gives the resulting scans a better resolution than normal CT-scans (Noel 2008, 18). As mentioned earlier we used synchrotron based micro CT for this experiment. The main difference between synchrotron-based µ-CT and conventional µ-CT is that synchrotron-based µ-CT uses an almost parallel beam and a photon flux (number of photons per second per unit area) several times higher than conventional µ-CT (Brunke 2008, 1-2). By making use of synchrotron based µ-CT some limitations of conventional µ-CT were by-passed: a common limitation of the use of conventional µ-CT is beam hardening. Beam hardening occurs when a polychromatic beam is used, which consist of a range of the energy spectrum, instead of a monochromatic beam, which consists of a very narrow wavelength, ideally of a single wavelength. Of the polychromatic beam the low energetic X-rays are more likely to be absorbed than the high-energetic X-rays. The hardening of the beam results in imaging artefacts. Imaging artefacts are misrepresentations of the data, which can be caused by a number of reasons. By making use of synchrotron-based µ-CT the chance of imaging artefacts is significantly reduced compared to conventional µ-CT (Barrett and Keat 2004, 1680-1681; Cnudde and Boone 2013, 7-8).

What is a synchrotron and how does it work?

A synchrotron is a particle electron accelerator that produces synchrotron radiation by the acceleration of electrons. During this acceleration the electrons lose energy in the form of light, called synchrotron radiation. This radiation is then used for various experiments (www.synchrotron-soleil.fr).

A synchrotron facility operates as follows: An electron gun fires a beam of electron, which first is accelerated in a linear accelerator, the linac. In this the electrons are brought to a high speed and reach an energy level of 100 MeV. Next the electrons enter the Booster, which is a circular accelerator. In the Booster the energy of the electrons is increased from 100 MeV to 2750 MeV. With this energy level the electrons are injected in the storage ring where they circulate. In the storage ring various magnets control the trajectory of the electrons by bending them. The circulating electrons lose energy in the form of light, this light is called synchrotron radiation. The light is then redirected to various beamlines. Each beamline is an independent laboratory (www.synchrotron-soleil.fr).

Collaborating with synchrotron (beamline) scientists

The use of a beamline comes with beamline scientists. The scientists are there to learn you how to carry out the experiment and mainly provide technical support, when there are problems with the hardware used in the experiment. They also provide support with the creation of the 3D representations of the data. Keep in mind that the beamline scientists do not carry out the analysis of the data itself. They are only there to provide support creating the 3D construction of the data.

Another thing to keep in mind when working with these scientists is that they are not archaeologists. Thus, it is important to know the physical properties of the samples and if the samples have been conserved in some way, since this can influence the resulting data. Furthermore it is crucial to know if the research can actually answer the research question.

Another issue to keep in mind is the size of the data that will be received. The raw data for one sample consisted for this experiment of 120 Gigabytes of data. This is because the scan consists of circa 5000 measurements. The large data size also means that a computer with a sufficient amount of memory is needed to process the data.

The preparation of the samples and the execution of the experiment

Because of the relatively large dimensions of the samples, both samples were placed on a plastic cap, which then was glued to a plastic screw. This functioned as the platform for the samples. Next the samples were covered with plastic foil to keep it in place during the scan. In this way no glue can come in contact with the samples, since glue could harm the samples. The next stage consisted of scanning the samples with the beamline.

The processing of the data

The data was analysed with the help of the program Avizo 9.2.0. Avizo is software for 3D visualisation and analysis. With Avizo it was possible to visualise the data and make a 3D reconstruction of the sample. The analysis and 3D visualisation were carried out at the Faculty of Civil Engineering and Geosciences of the TU Delft.

4.2. Scanning Electron Microscopy (SEM)

How does it work?

Scanning Electron Microscopy (SEM) is a type of microscopy that uses a beam of high-energy electrons. This beam is guided and focussed with electromagnetic optics. The detector collects the electrons that come from the sample, either the direct scatter (Secondary Electron Image: SEI) or the emitted electrons from the sample (Backscattered Electron Image: BEI). An image is created based on the energy of the detected electron with their intensity and location of emission (Mehta 2012, 17).
The SEM can be equipped with an Energy Dispersive X-ray Spectrometry detector (EDX), which is used for elemental analysis. The principle is based on the atomic number of the elements and the difference in energy between the electron within the sample and the higher energy electron from the x-rays that replaces the other electron. The number and the energy of the x-rays emitted by the sample are measured by an energy-dispersive spectrometer. The difference in energy between the x-rays and the atomic structure of the measured element are characteristic for that specific element that enables the EDX to differentiate between the different elements (Mehta 2012, 22).
Chemical analysis with SEM-EDX can give us information about the elements present in the textile and in which quantities they are present, among which are pigments, mordants and salts (Jones *et al.* 2007, 248).

Sample preparation and the analysis of the samples

The samples were mounted on a platform with a small piece of double-sided carbon tape. The images were made with a FEI Nova NanoSEM 450 (laboratory of the RCE, Amsterdam). This is a variable pressure SEM (VP-SEM) which gives the possibility to work under different pressures. Due to a small amount of gas that remains in the sample chamber, charging of the object can be avoided. With the use of a VP-SEM it is not needed to coat the object with a conductive coating. In a conventional SEM non-conductive materials, such as complete organic materials (which textiles are), need to be coated with a conductive layer such as gold or carbon (Fischer 2010, 97). EDX analysis was done by a silicon drift detector from Thermo Scientific using NSS software.

5. Results

5.1. Results of the SEM images

In the next paragraphs I will give an overview of the results of the imaging with SEM and the chemical analysis carried out with the SEM-EDX.

5.1.1. Sample Oss-G

When sample Oss-G was prepared to be analysed with the SEM it was very clear that this sample is very fragmented. In the find bag numerous fragments from the sample were present.

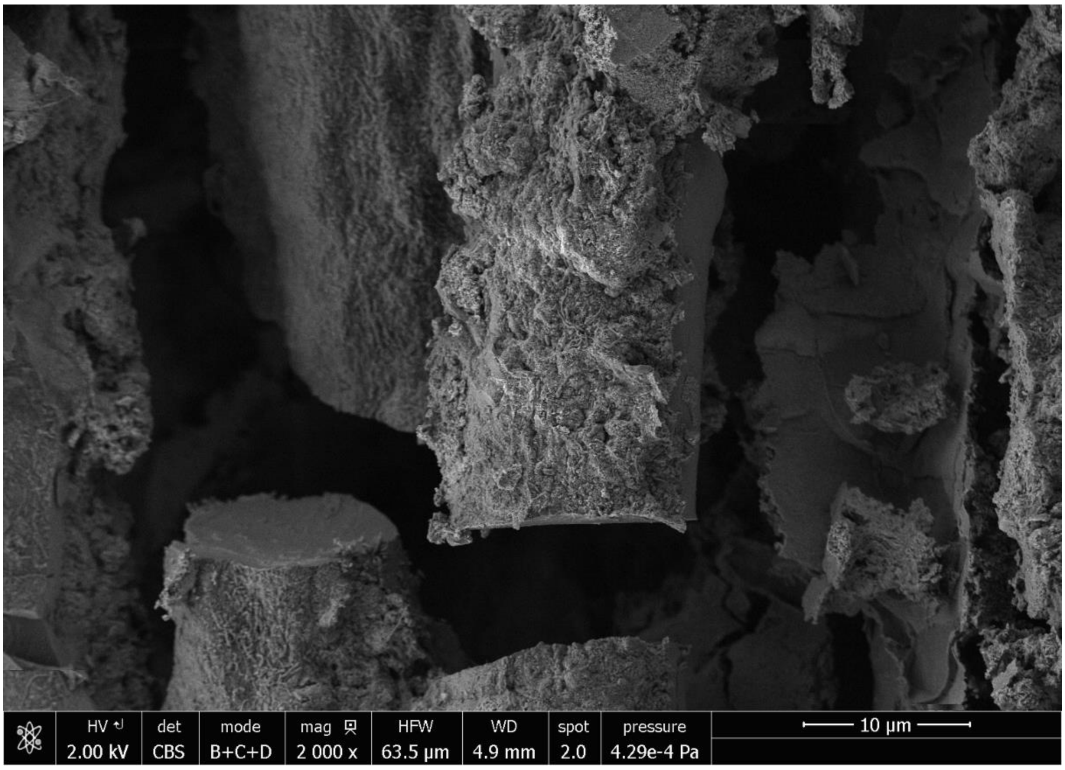


Figure 17 Close-up of the very fragmented fibres of sample Oss-G (© Cultural Heritage Agency)

Preservation of the sample

When analysed with the SEM, it became clear that the fibres from sample Oss-G are also fragmented and show various breaks. After extensive mineralisation it is hard to determine the presence and preservation of the scales on the wool fibres. The presence and preservation of the scales of the wool would give an indication of the use-wear of the textile. The use-wear can be further researched by looking at the degree of fibre fracture. Different types of use result in different types of use-wear (Cooke and Lomas 1990, 215-226). In figure 17 the negative cast of possible scales is visible. This shows that the scales of the wool are present underneath the mineralisation. Still with the extensive mineralisation it was not possible to obtain an accurate idea of the preservation of the scales.

Chemical analysis of sample Oss-G

On both samples a chemical analysis is carried out to determine by what the textiles were mineralised and if there are traces of a mordant.

The chemical analysis of sample Oss-G was carried on six different places (app. 1). The analysis shows various peaks of iron (Fe) and copper (Cu). The copper and iron likely originate from the metal objects. The other elements shown in the diagram likely originate from the soil.

We have to take into account that the researched sample might have been consolidated with paraloid. This would lead the SEM-EDX to measure the consolidant instead of the sample itself. This could lead to unexpected peaks in the chemical analysis.

After carefully removing the sample from the carbon tape once again it was clear that the material is very fragmented.

5.1.2. Sample Slabroek-70A

The sample Slabroek-70A looks significant less fragmented to the naked eye than the fragment of Oss-G. This is possibly caused by the chemicals used to conserve the textile fragments.

Figure 18 Close-up of the substance covering the fibres of sample Slabroek-70A (possibly the PVAc) (© Cultural Heritage Agency)

Preservation of the sample

When we looked at the sample of Slabroek-70A the scales normally present on wool fibres, were almost invisible. The fibres of the textile fragment are covered with a substance, as shown in figure 18. This is probably the preservative used during the conservation. The substance makes it impossible to obtain an accurate idea of the preservation of the sample.

Possible contamination?

In the sample of Slabroekse Heide I came across donut shaped features (fig. 19 & 20). Interestingly, these donut shapes are present underneath the preservative, which means that it is likely that the donut shapes were present in the sample before the conservation of the textile fragment. This means that the contamination must date before the conservation in 2011 (Restaura bv. 2011, 11). This makes it more likely that the donut shapes got into the textile during the use of the textile or when the textile

fragment was in the ground.
It was impossible to determine if the donut shapes are also covered by the mineralisation. If the donut shapes are covered by the mineralisation this would mean that the donut shapes were present before the textile was mineralised, which makes it more likely that the donut shapes were present in the textile during the use life of the textile or when the textile was in the grave before the mineralisation had started.
An interesting fact is that the same donut shapes were found in very low amounts in the sample of Oss-G (app. 2). This makes it likely that the donut shapes did not end up in the textile during the use of the textile but rather originate from the soil. The possible interpretation of the donut shapes I will discuss in chapter six.

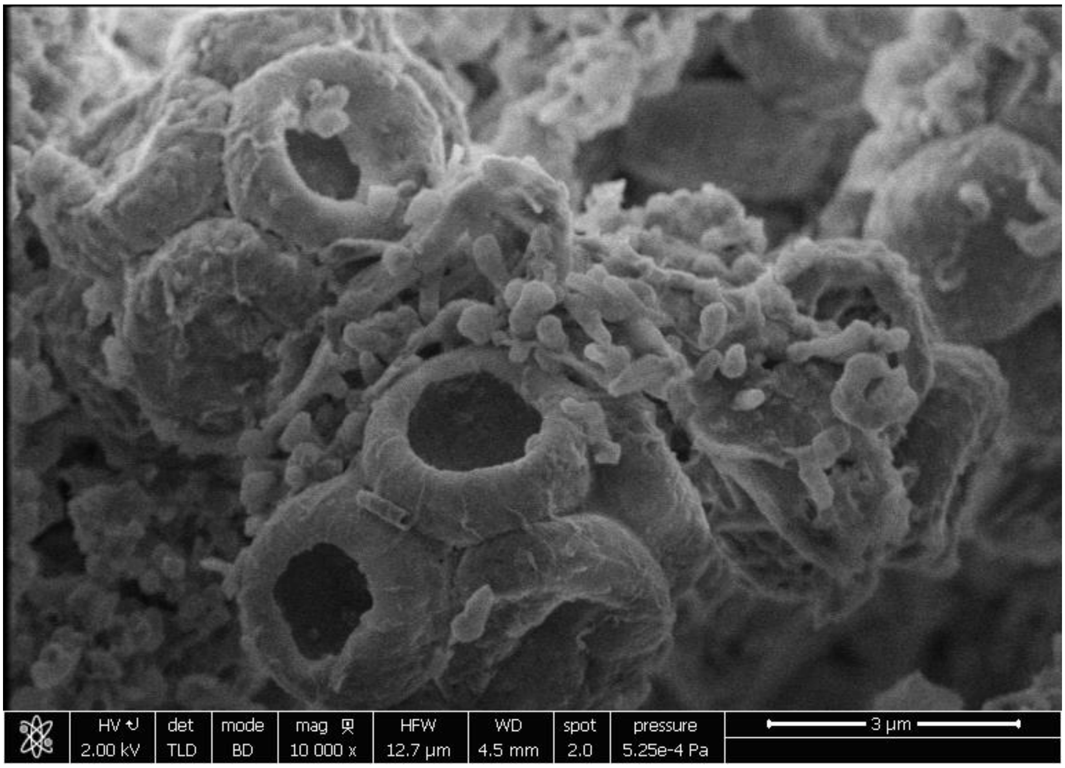


Figure 19 Close-up of the donut shapes present in sample Slabroek-70A (© Cultural Heritage Agency)

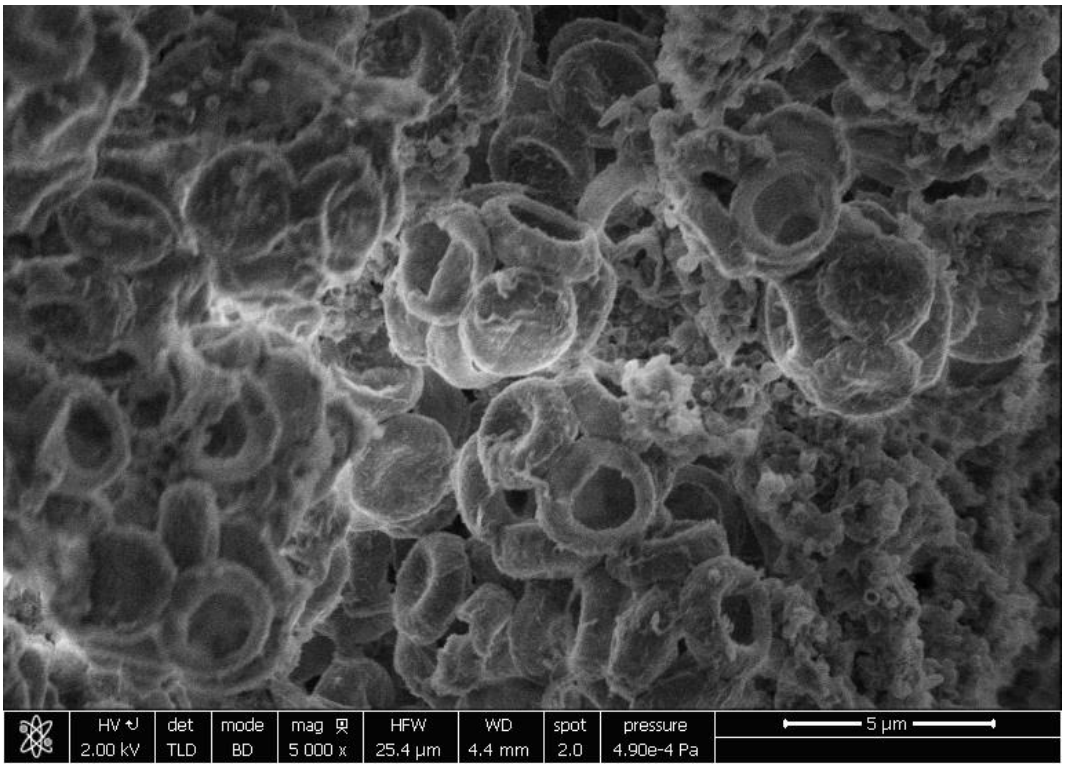


Figure 20 The clustering of the donut shapes in sample Slabroek-70A (© Cultural Heritage Agency)

Chemical analysis of sample Slabroek 70A

With SEM-EDX a chemical analysis of the sample was carried out on four different places (app. 3). The chemical analysis showed various peaks at iron (Fe) and copper (Cu). This confirms that the textiles were mineralised by copper and iron. The copper likely originates from the bronze bracelet, while the iron could originate from the soil. The other elements shown in the diagram likely originate from the soil. We have to take into account that the researched sample might have been consolidated with PVAc. This would lead the SEM-EDX to measure the consolidant instead of the sample itself. This could lead to unexpected peaks in the chemical analysis.

5.2. Results of the 3D reconstruction of the micro-CT scans

The µ-CT data received consist of a series of 2D slices (fig. 21). These slices together form the complete dataset.

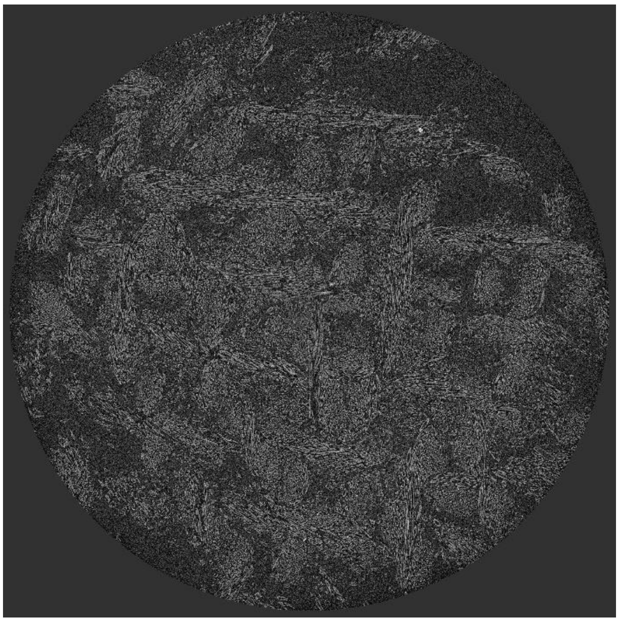


Figure 21 A 'slice' of sample Oss-G (figure by author)

The process of creating the 3D reconstructions

The 3D reconstruction of both samples did not go without problems, with a main factor being the size of data. Even with a Dell station, a computer with a large memory and CPU specialised for image processing, it was impossible to process the whole dataset at the same time. Thus, I was forced to subdivide the dataset of each sample in sixteen more manageable pieces and look at them separately. Another drawback of the data size is that every action takes a long time to buffer. For this reason it is a good idea to first try a possible action on a small part of the sample and when the action is satisfactory, to try the same action on a larger part. Another problem occurs when too big a sample is tried to be processed. This will make the computer freeze and crash. After selecting the right method on how to display the data in Avizo, the reconstruction of a 3D image of both samples was straight forward.

In the following paragraphs the results of the 3D reconstructions will be presented of the samples of Oss-G and Slabroek 70A.

5.2.1. The 3D reconstruction of sample Oss-G

The resulting 3D image gives the possibility to look at the sample from all angles. It is also possible to crop at any place in the sample to obtain a cross section, which is again viewable from all angles. With the 3D image it is possible to study the individual fibres within the threads, the degree of twist of the threads and the weave structure of the textile. Furthermore if the textile consists of multiple layers folded or packed, it is still possible to study the structure of each individual layer. This information can be used to determine how the textile would have looked and for what the textile was used for.

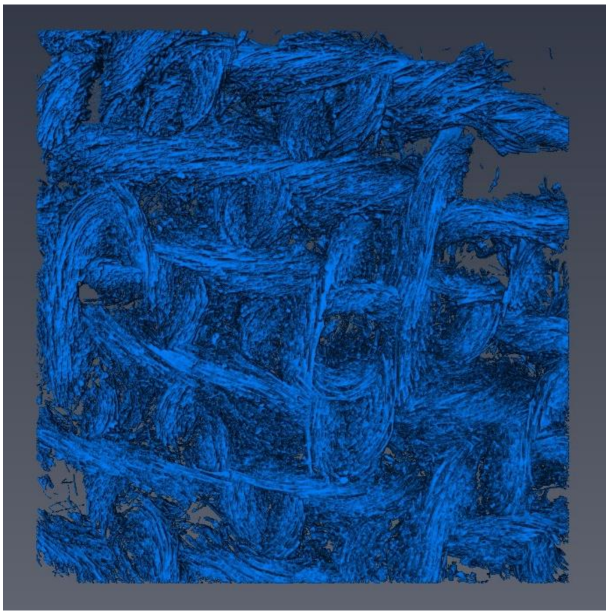


Figure 22 Cross section of sample Oss-G (figure by author)

In figure 22 the longitudinal cross section of Oss-G gives a clear image of the weave structure of the textile.

5.2.2. The 3D reconstruction of sample Slabroek 70A

The 3D reconstruction of sample Slabroek 70A gave a very different image than the reconstruction of sample Oss-G. The sample of Slabroek looks very chaotic compared to sample Oss-G, with no clear weave pattern visible in the cross section as is shown in figure 23.
An explanation for this could be that the sample of Oss-G is of a higher quality or that the sample is less degraded than the sample of Slabroekse Heide. Another explanation could be that what we see is the use-wear or evidence that the textile of Slabroekse Heide was felted.

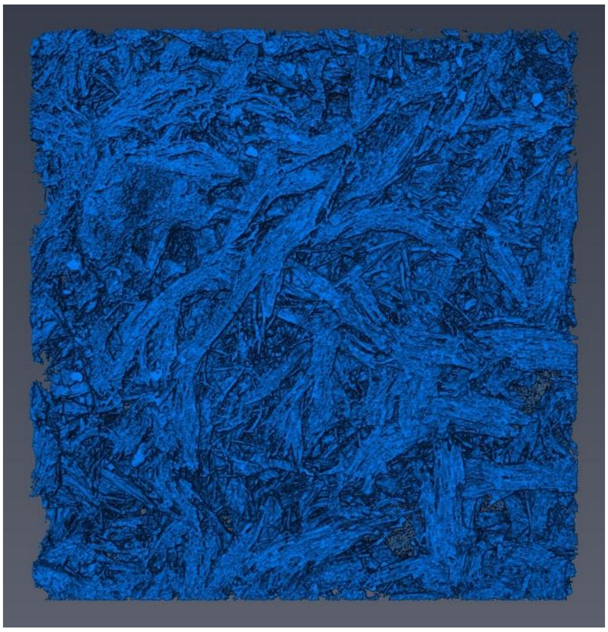


Figure 23 Cross section of sample Slabroek 70A (figure by author)

Interestingly, in her textile analysis of the sample of Slabroek 70A, Grömer notes that the same sample has a rubbed off and worn out look and appears to be felted inside and outside. Grömer reasons that this happened due to a degradation process or use-wear (Grömer 2015, 18).

6. Analysis and discussion

In the previous chapter the results of the analysis of the SEM and the 3D representation were addressed. Still many questions remain, which are considered here.

What could be a viable interpretation of the donut shapes?

To determine what the donut shapes could be, I asked advice from various experts, among others botanical specialists, a mycologist and a specialist in non-pollen palynomorphs. It was suggested that the shapes might be coccoliths, which are plates of calcite that serve as the exoskeleton of a species of marine algae, coccolithophores (fig. 24). This was however rendered unlikely by a specialist on coccoliths[4].

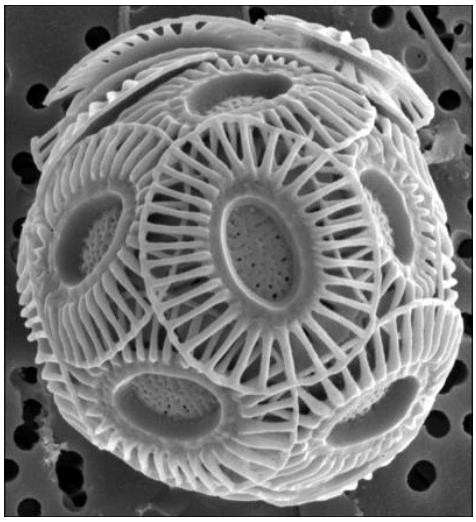


Figure 24 A cluster of Coccoliths (http://oceanleadership.org)

Another hypothesis is that the shapes could be pollen or non-pollen palynomorphs (organic microfossils that are not pollen). This has since been proven less likely since both a pollen expert[5] and an expert on non-pollen palynomorphs[6] did not recognise the shapes as pollen or non-pollen palynomorphs respectively.
A third hypothesis is that the shapes could be insect eggs. An entomoarchaeological expert[7] theorised, however, that is unlikely that the shapes are from an entomological origin, since insects eggs are often many times larger.
A last hypothesis seemed at first the most unlikely. Based on the appearance of the donut shapes, I hypothesised that the shapes might be red blood cells, which is seen as very unlikely since red blood cells perish very easily. A first argument that the shapes could not be red blood cells was the size of the shapes, which is about 3-4 µm, while human red blood cells have a diameter of about 7-8 µm. Thus it is highly unlikely that if the shapes are red blood cells, that they are human. Interestingly, various species of animals have a diverse range of diameter of red blood cells. Based on the diameter of the shapes a viable option could, for example, be the common goat, *capra hircus.* The

[4] Pers. comm. Dr. Jeremy Young (specialist on coccoliths) of University College London
[5] Pers. comm. Marieke Doorenbosch (specialist on pollen) of Leiden University
[6] Pers. comm. Dr. Bas van Geel (specialist on non-pollen palynomorphs) of University of Amsterdam
[7] Pers. comm. Drs. T. Hakbijl (specialist on entomoarchaeology) of Naturalis

goat's blood has red blood cells with a diameter of circa 3-4 µm (www.genomesize.com). Thus, based on the size of the donut shapes it is not possible to exclude red blood cells as a viable theory.

In an effort to be able to excluded the red blood cells as a plausible hypothesis, I asked the advice of an expert on the study of haematology with SEM[8]. He came to the conclusion that the shapes do look like red blood cells and, if they are actually red blood cells, they are very well preserved.

He also noted that it is very unlikely that the shapes are red blood cells since if red blood cells are not fixated immediately, they usually start to show changes, which are not visible in our sample. The expert also noted that the absence of these changes does not exclude the possibility of the donut shapes being red blood cells. Further research is needed to determine if the donut shapes are actually red blood cells or that this hypothesis can be fully discarded.

How do the 3D reconstructions compare with the technical analysis?

The technical analysis by Grömer described sample Slabroek 70A as possibly being felted, which might have been caused by degradation or use-wear. The same worn look can be seen in the 3D representation of the sample. In the 3D representation the individual threads are hardy distinguishable. This corresponds with the Grömer's remark that it likely has been a warm and soft textile (Grömer 2015, 18).

The technical analysis which describes sample Oss-G overall corresponds with can be seen in the 3D representation of the sample. Though, the low twist of threads and the traces of use-wear or degradation are not visible in the 3D representation. Grömer notes that these traces are not visible on all fragments of textile G, thus it is possible that sample Oss-G does not show these features (Grömer 2015, 15).

Was the carried out consolidation and preservation process the best method for the textile fragments?

Both the textile fragments of Oss-Vorstengraf and Uden-Slabroekse Heide were to an extent conserved. Some of the fragments of Oss-Vorstengraf were treated with paraloid during a conservation attempt in 1993, although it is unclear precisely which fragments were treated (Kempens and Lupak 1993, 53-54). The textile fragments of Uden-

[8] Pers. comm. Em. Prof. Aaron Polliack (specialist on the use of SEM in haematology) of the Hebrew University of Jerusalem

Slabroekse Heide were directly conserved with a 10% solution of PVAc, after they were removed from the bronze bracelets and anklets (Restauratieatelier Restaura 2011, 11). The question remains whether the practised conservation process was the best method for both the textiles to recover information from the textiles. On the one hand, it is noted that all of the textile fragments are extremely fragile and even when handled with the greatest care, slowly fall apart. Thus, to preserve the textiles and their structure it was a good choice to conserve them. On the other hand, the conservation process has made determining the degree of preservation of the textiles with the help of SEM significantly harder. Because of the preservative used, it is impossible to tell if the fibres show micro-factures. Furthermore by directly consolidating the fragments the results of future chemical analyses are affected (Jones *et al.* 2007, 248).

What is the added value of using µ-CT scanning in the study of archaeological textiles and do the results of creating them outweigh the costs and efforts to create them?
By using µ-CT to study archaeological textiles it is possible to create a 3D representation, which can be used to thoroughly study the structure of the textile, since the image can be studied from all angles and provides the ability to make various cross-sections.
Still, the question remains if the results of creating µ-CT of an object outweigh the costs and efforts to create them. To create a 3D representation of the object the object has to be scanned with µ-CT equipment. The resulting data are then processed with specialised software, such as Avizo or Fiji: Just ImageJ. For the analysis of the data a computer is needed with sufficient memory to process the data and to create the 3D image.
The µ-CT data used in this research was created at the synchrotron facility SOLEIL in Saint-Aubin, France. Access to the various laboratories, called beamlines, is available to scientists around the world through submitting a proposal, which is reviewed by a Peer Review Committee. There are no costs related to utilising the beamline if the results are open for publication (www.synchrotron-soleil.fr). Still, to create the data one has to travel to France with the samples for this specific beamline and have the opportunity that one's research proposal is selected.
Though further research is needed to determine if conventional µ-CT equipment can create accurate 3D representations of mineralised textile fragments, based on the accessibility of the equipment and the costs involved to scan an object with conventional µ-CT equipment, it is a more viable option for regular use, since the equipment is commonly used. To scan an object with the micro CT equipment at the

Faculty of Civil Engineering and Geosciences of the TU Delft a fee of €250 is required[9]. The total costs depend on many factors, such the amount of samples to be processed and the complexity of a scan. With commercial companies the cost of a scan can be anywhere between €100 and €1000 and at universities between €50 and €500 (microctworld.net).

Still, these are only the costs of creating the data. The data still has to be analysed to create an 3D representation of the sample. For this specialised software has to be used, of which the most commonly used are Fiji: Just ImageJ and Avizo, of which Avizo was used in this research.

The time it takes to create a 3D representation of the sample is highly variable. It can take up from one hour to a hundred and depends on how precise the analysist wants to make the 3D representation. Still, because of the greater availability of conventional μ-CT equipment, it makes the technique a more viable option to be used regularly, than synchrotron-based μ-CT equipment.

The question remains if the results of the 3D representations are worth the costs and efforts to create them. The worth of the 3D representation is fully dependent on the textile fragment that is scanned. Since the 3D representation is most useful to study the structure of textiles, most information can be gained when used on packed textiles (multiple layers of textiles preserved against one other) or when the textiles are highly degraded on the surface. Furthermore it could prove a useful method to study degraded textiles preserved on metal objects, which would be lost during the preservation of the metal objects.

Still, to fully assess the potential of the creation of 3D representations further research is needed.

Did the research add to our interpretation of the textiles and what could this mean for our interpretation of the sites?

While the creation of 3D representations of the samples did not specifically add to our interpretation of the textiles, the thorough re-examination of the technical analysis of the textiles did. By summarising the previous analysis of the textiles, I came across an interesting fact on the dyestuff analysis of the textiles of Uden-Slabroekse Heide, which was considered to be the only one carried out to date. As mentioned before, the

[9] Pers. comm. Dr. Ir. Dominique Ngan-Tillard of the Faculty of Civil Engineering and Geosciences of the TU Delft.

dyestuff analysis carried out by Nientker and van Bommel resulted in a unidentified red dyestuff on the textiles of find numbers 58, 70 and 71 (Nientker *et al*. *in press*, 2-3). Interestingly, Grömer identified both a red and a blue dyestuff on a textile of number 72. Grömer also noted that a pattern is countable of alternating light and dark strings. This made her identify the pattern as possibly bright red and blue block checks (Grömer 2015, 19-20). To further establish the colours of the textile, I advise to carry out another dye stuff analysis to confirm the dyes found by Grömer.
The summarize, this research confirmed the established interpretation of both the textiles and the sites.

Can the applied techniques provide information about how Oss-Vorstengraf and Uden-Slabroekse Heide could fit into the Hallstatt cultural network?
The question remains if the applied techniques can provide information about both sites could fit into the Hallstatt cultural network. In other words, can the applied technique help us tell if the textiles are locally produced or imported?
On their own, the applied techniques cannot tell us if the textiles are imported or not. Still, when these techniques are applied in a wider research, for example, to compare the structure of the textiles from Oss-Vorstengraf and Uden-Slabroekse Heide with other Hallstatt sites it is possible.

7. Conclusion

The main aim of this thesis was to take a first step into studying the possibilities of the use of Micro Computed Tomography in the study of archaeological textiles.
For this the textiles of the Early Iron Age sites Oss-Vorstengraf and Uden-Slabroekse Heide were studied. These sites have a precise dating and thoroughly documented context information. These burial differ from other burials, since the burial of Uden-Slabroekse Heide is an inhumation burial, where cremation is the norm, while burial of Oss-Vorstengraf is a princely grave, characterised by the imported *situla* and Mindelheim-type sword. The burials considered have brought forth remarkably rich grave goods, among which are numerous mineralised textile fragments.

This thesis has proven that it is possible to create accurate 3D representations of mineralised archaeological textiles, the twist of the threads and the individual fibres. The 3D representations can be used to thoroughly study the structure of the textile. To study the structure of a textile, a 3D image is more informative than SEM, since the image can be studied from all angles and provides the ability to make various cross-sections. To assess the preservation of the textile and the determine the source of the fibres, SEM is the most optimal technique to be used, since it provides the required view of the surface which is lost with the micro CT.
For this reason I recommend to use a combination of micro CT and SEM to study archaeological textiles. Still further research is needed to assess whether the use of μ-CT outweigh the costs and efforts involved.

8. Recommendations for future research

This thesis consisted as just the first step into the use of Micro Computed Tomography in the study of archaeological textiles. Still, further research has to be carried out to fully assess the potential of the use of Micro Computed Tomography to study archaeology textiles. In the following I summarise the questions that have come forth during this research.

Synchrotron based μ-CT versus conventional μ-CT

In this thesis I made use of synchrotron-based Micro Computed Tomography. For future research it would be interesting to look into the possibilities of the use of conventional μ-CT equipment for the 3D reconstruction of archaeological textiles. Conventional μ-CT is more accessible, since μ-CT equipment is more common and conventional μ-CT scans often result in a smaller data size to be processed, which in turn requires a less powerful computer than the one needed to process synchrotron based μ-CT data. Still further research is needed to determine whether it is possible to reach the same result with conventional μ-CT equipment as with synchrotron-based μ-CT equipment.

Highly degraded textiles on metal objects and textiles in situ

The use of Micro Computed Tomography could be a valuable tool to obtain information from archaeological textiles. This applies especially in the case of highly degraded textiles preserved on metal objects that will be lost during the preservation of the metal objects. If it is possible to create an accurate 3D image of the textile when it is still attached to a metal object or still in a block, it would rescue the information that can be gained from the textile. With highly fragmented textiles, the textile is often damaged or completely lost when the attached metal object is preserved. The question remains how the 3D representation turns out with the significant difference in density between the mineralised textile and the metal object. Since mineralised textiles are significantly less dense than the metal objects, there is a chance that the presence of metal objects lead to severe streaking artefacts, which are black strokes in the resulting image. Still with specialised software it is possible to minimise the distortion of the 3D image (Barret and Keat 2004, 1685). A first step would be creating a μ-CT scan of a metal object with the textile still attached and see to what extent a clear and accurate 3D representation of the textile fragments can be created. The next step would be to create a μ-CT scan of the textiles attached to the metal object with the surrounding soil and see if this still gives a clear and accurate 3D image. If it is possible to create an accurate 3D representation of the block, it could provide important information about the placement of the objects in the block and could replace the radiographs, which are commonly used by restorers to determine the position of the metal object in the block.

How do the sites of Oss-Vorstengraf and Uden-Slabroekse Heide fit into the Hallstatt cultural network based on their textiles?

The question remains how the textiles of Oss-Vorstengraf and Uden-Slabroekse Heide fit into the Hallstatt cultural network. In other words, are the textiles locally produced or are they imported from the Hallstatt culture region? If they are imported, Through a comparative study of the textiles of other burials with links with the Hallstatt region, the likelihood that these textiles were imported can be assessed. This can, for example, based on the fineness of the wool, by measuring the diameter of at least a hundred fibres (Rast-Eicher and Bender Jørgensen 2013), or based on the fineness of the weave of the textile (Grömer 2016, 115).

Abstract

In this thesis the added value of using µ-CT scans in the study of archaeological textiles is studied. To study the potential of this technique, two samples of the textiles from the sites of Oss-Vorstengraf and Uden-Slabroekse Heide were analysed. These Early Iron Age sites are among the few prehistoric sites that have brought forth preserved archaeological textiles. The sites were chosen because of their precise dating and their thoroughly documented context information. The textiles fragments of both sites have been mineralised through their contact with metal objects and thus have been mineralised.

For this research the two samples were scanned with µ-CT at a synchrotron facility. The µ-CT data was used to create 3D representations of the scanned textiles. The potential of µ-CT in the study of archaeological textiles was assessed by comparing the 3D representations of the textiles, with the results of the analysis with SEM, Scanning Electron Microscopy, and the results of the technical analysis of the same samples.

With the 3D representations of the textiles, it is possible to thoroughly study the structure of a textiles from all possible angles and it provides the ability to create cross-sections of the textile.

To assess the preservation of the textile and the determine the source of the fibres, SEM is the most optimal technique to be used, since it provides the required view of the surface of the individual fibres, which is lost with the 3D representations.

Still, when using µ-CT to study archaeological textiles, the costs and efforts to create the 3D representations should be taken into account.

In the future, the combination of µ-CT and SEM might prove to be a valuable combination to study archaeological textiles.

Samenvatting (Dutch summary)

In deze scriptie is gekeken naar de meerwaarde van het gebruik van µ-CT scans bij de bestudering van archeologisch textiel. Om het potentieel te bepalen van deze techniek zijn twee samples van de sites Oss-Vorstengraf en Uden-Slabroekse Heide geanalyseerd. Deze vroege IJzertijd sites behoren tot de weinige prehistorische sites welke archeologisch textiel hebben voorgebracht. Deze sites zijn gekozen vanwege hun goede datering en goede context gegevens. De textiel fragmenten van beide sites zijn bewaard gebleven door contact met metalen objecten, waardoor ze zijn gemineraliseerd.

Voor dit onderzoek zijn de twee textiel samples gescand met µ-CT in een synchrotron faciliteit. De µ-CT data is vervolgens gebruikt om 3D reconstructies te maken van de samples.

Het potentieel van µ-CT voor de bestudering van archeologisch textiel is beoordeeld door de 3D reconstructies te vergelijken met de resultaten van de analyse met rasterelektronenmicroscopie, SEM, en de resultaten van de technische analyse van dezelfde samples.

Met de 3D reconstructies van de textiel samples, is het mogelijk om grondig de structuur van het textiel te bestuderen vanuit alle mogelijke hoeken. Verder geeft de 3D reconstructie ook de mogelijkheid om doorsnedes de maken van het textiel.

Voor het bepalen in welke mate het textiel is bewaard is gebleven en welke ruwe vezel is gebruikt in het textiel, is rasterelektronenmicroscopie beter om te gebruiken, aangezien het een beeld geeft van het oppervlak van de individuele vezels. Bij de 3D reconstructies is echter het oppervlakte van de vezels verloren.

In de toekomst kan mogelijk een combinatie van beide technieken uitkomst bieden bij de bestudering van archeologisch textiel.

Internet pages

http://genomesize.com/cellsize/mammals.htm, accessed on 30-05-2017.

http://ipanema.cnrs.fr/ipanema-13/article/the-ipanema-lab, accessed on 02-04-2017.

http://microctworld.net/the-costs-of-a-microct-scan/, accessed on 08-06-2017.

http://oceanleadership.org/related-reading-co2-makes-life-difficult-for-algae-coccoliths-dissolve-when-seawater-acidifies/, accessed on 11-06-2017.

http://serc.carleton.edu/research_education/geochemsheets/techniques/CT.html, accesses 15-04-2017

https://synchrotron-soleil.fr/en/users/application-beamtime/access-mode, accessed on 30-05-3017.

https://synchrotron-soleil.fr/en/soleil-3-questions, accessed on 07-03-2017.

Bibliography

Andersson Strand, E., K.M. Frei, M. Gleba, U. Mannering, M. Nosch and I. Skals, 2010. Old textiles new possibilities. *European Journal of Archaeology* 13(2), 149-173.

Barrett, J. F. and N. Keat, 2004. Artifacts in CT: Recognition and Avoidance. *RadioGraphics* 24, 1679-1691.

Baumann, R., D.C. Porter and W.B. Seales, 2008. The use of Micro-CT in the study of archaeological artefacts. 9th International Conference on NDT of Art 25-30 May 2008, 1-9.

Belanová-Štolcová, T.B. and K. Grömer, 2010. Loom-weights, Spindles and Textiles – Textile Production in Central Europe from the Bronze Age to the Iron Age, in E. Andersson Strand, M. Gleba, U. Mannering, C. Munkholt and M. Ringgaard (eds), *North European symposium for archaeological textiles X.* Oxford: Oxbow books (ancient textiles series vol. 5), 38-51.

Bender Jørgensen, L., 1992. *North European Textiles until AD 1000*. Aarhus: Aarhus University Press.

Broudy, E., 1979. *The book of Looms: A History of the Handloom from Ancient Times to the Present*. Wokingham: Van Nostrand Reinhold Company Limited.

Brunello, F., 1973. *The art of dyeing in the history of mankind*. Vicenza: Neri Pozza Editore.

Brunke, O., 2008. Comparison between X-ray tube based and synchrotron radiation based µCT, in S.R. Stock (ed), Developments in X-Ray Tomography VI, August 10 2008. San Diego, California, USA.

Cnudde, V., and M.N. Boone, 2013. High-resolution X-ray computed tomography in geosciences: a review of the current technology and applications. *Earth-Science Reviews* 123, 1-17.

Cooke, B. and B. Lomas, 1990. The evidence of wear and damage in ancient textiles, in P. Walton and J. Wild (eds), *Textiles in Northern Archaeology: NESAT III Textile Symposium in York 6-8 May 1987*. London: Archetype Publications (North European Symposium for Archaeological Textiles Monograph 3), 215-226.

Eicher, J.B. and M.E. Roach-Higgins, 1992. Definition and Classification of Dress: Implications for Analysis of Gender Roles, in R. Barnes and J.B. Eicher (eds), *Dress and Gender: Making and Meaning in Cultural Contexts.* Oxford (UK): Berg Publishers, Inc. 8-28.

Fischer, A., 2010. Current Examinations of Organic Remains using Variable Pressure Scanning Electron Microscopy [VP-SEM}, in E. Andersson Strand, M. Gleba, U. Mannering, C. Munkholt and M. Ringgaard (eds), *North European symposium for archaeological textiles (NESAT) X.* Oxford: Oxbow books (ancient textiles series vol. 5), 96-105.

Fokkens, H., S.A. van der Vaart, D.R. Fontijn. S.A.M. Lemmers, R. Jansen. I.M. van Wijk and P.J.C. Valentijn, 2012. Hallstatt burials of Oss in context, in C. Bakels and H. Kamermans (eds), *The end of our fifth decade.* Leiden (NL): Faculty of Archaeology, Leiden University (Analecta Praehistorica Leidensia 43/44), 183-204.

Good, I., 2001. Archaeological Textiles: A review of Current Research. *Annual Review of Anthropology 30,* 209-226.

Grömer, K., 2015. *Hallstat Period Textile Finds from The Netherlands.* Internal report Natural History Museum Vienna.

Grömer, K., 2016. *The Art of Prehistoric Textile Making: The development of craft traditions and clothing in Central Europe.* Vienna: Natural History Museum Vienna.

Hald, M., 1980. Ancient Danish Textiles From Bogs And Burials: A Comparative Study of Costume and Iron Age Textiles. *Archaeological-Historical Series Vol. XXI*. Publications of The National Museum, Denmark.

Harris, S., 2010. Smooth and Cool, or Warm and Soft: Investigating the Properties of Cloth in Prehistory, in E. Andersson Strand, M. Gleba, U. Mannering, C. Munkholt and M. Ringgaard (eds), *North European symposium for archaeological textiles X.* Oxford: Oxbow books (ancient textiles series vol. 5), 156-163.

Jansen, R., H. Fokkens, J.W. de Kort and E. Smits, 2007. Het vorstengraf van Oss re-reconsidered: Arhceologisch onderzoek Oss-Vorstengrafdonk 1997-2005. *Archol rapport 49*. Faculteit der Archeologie Universiteit Leiden and Archol bv, Leiden.

Jansen, R., Q. Bourgeois, S. van der Vaart and W. Verschoof, in press. Buiten de norm? Een ‘rijk’ inhumatiegraf in het vroege ijzertijd urnenveld Slabroekse Heide – opgraving, resultaten en interpretatie, in R. Jansen (ed), *Heidense Heuvels: Het vroege ijzertijd en Romeinse tijd grafveld Slabroekse Heide.* Leiden.

Jones, J., J. Unruh, R. Knaller, I. Skals, L. Raeder Knudsen, E. Jordan-Fahrbach and L. Mumford, 2007. Guidelines for the Excavation of Archaeological Textiles, in C. Gillis and M. B. Nosch (eds), *Ancient Textiles: Production, Craft and Society: Proceedings of the First International Conference on Ancient Textiles, held at Lund, Sweden, and Copenhagen, Denmark, on March 19-13, 2003.* Oxford: Oxbow Books, 245-253.

Joosten, I., 2016. *Research report: Textile from the Chieftain’s burial of Oss, Identification of dyestuff and the condition of the fibres.* Internal report Cultural Heritage Agency.

Kempens, J. and T. Lupak, 1993. *Restauratie report Oss-Vorstengraf*. Restauratie rapportage. Restauratieatelier Restaura bv., Heerlen.

Mehta, R., 2012. Interactions, Imaging and Spectra in SEM, in V. Kazmiruk (eds), *Scanning Electron Microscopy.* Rijeka (Croatia): InTech Europe, 17-30.

Nientker, J., R. Jansen and S. van der Vaart, in press. Bijzondere textielvondsten uit het vroege ijzertijd inhumatiegraf uit Uden-Slabroekse Heide: kleding en lijkgewaad?, in R. Jansen (ed), *Heidense Heuvels: Het vroege ijzertijd en Romeinse tijd grafveld Slabroekse Heide.* Leiden.

Rahmstorf, L., 2015. An introduction to the investigation of archaeological textile tools, in E. Andersson Strand and M. Nosch (eds), *Tools, Textiles and Contexts: Investigating Textile Production in the Aegean and Eastern Mediterranean Bronze Age.* Oxford: Oxbow books (ancient textiles series vol. 21), 1-23.

Rast-Eicher, A. and L. Bender Jørgensen, 2013. Sheep wool in Bronze Age and Iron Age Europe. *Journal of Archaeological Science* 40, 1224-1241.

Remouchamps, A.E., 1924. Opgraving van een urnenveld te Uden (N.BR.). *Oudheidkundige mededelingen uit 's rijksmuseum van oudheden te Leiden,* 69-76.

Restaura bv., 2011. *Restauratie report Uden-Slabroekse Heide*. Restauratie report. Restaura bv., Heerlen.

Roymans, N., 1991. Late Urnfield Societies in the Northwest European Plain and the expanding networks of Central European Hallstatt Groups, in N. Roymans and F. Theuws (eds), *Images of the past: Studies on Ancient Societies in Northwestern Europe.* Amsterdam: University of Amsterdam (Studies in Pre- en Protohistorie 7), 9-90)

Vaart, S. van der, 2011. *Hail to the Chieftain. A detailed examination of grave goods from Dutch chiefly burials and their role in funerary rituals during the Hallstatt period.* Leiden (unpublished master thesis University of Leiden).

Walton, P. and G. Eastwood, 1984. *A brief guide to the cataloguing of archaeological textiles*. York: Wordplex Wordprocessing Bureau Ltd.

Walton Rogers, P., 1997. *Textile Production at 16-22 Coppergate.* York: York Archaeological Trust for Excavation and Research (The Archaeology of York Vol. 17: The Small Finds).

Wijk, van, I.M. and R. Jansen, 2010. Het urnenveld Slabroekse Heide op de Maashorst; Een verkennend en waarderend archeologisch proefsleuvenonderzoek. *Archol-rapport 72*. Archol bv, Leiden.

Wild, J.P., 1988. *Textiles in Archaeology.* Aylesbury: Shire Publications LTD.

Figures

Tables

Appendices

Appendix I: Chemical analysis of sample Oss-G of Oss-Vorstengraf

Oss G(1)

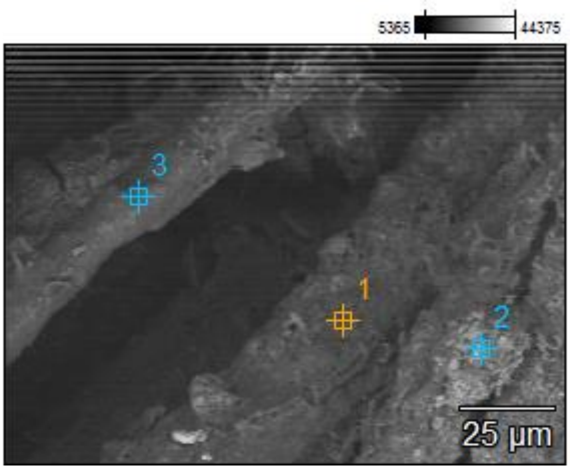
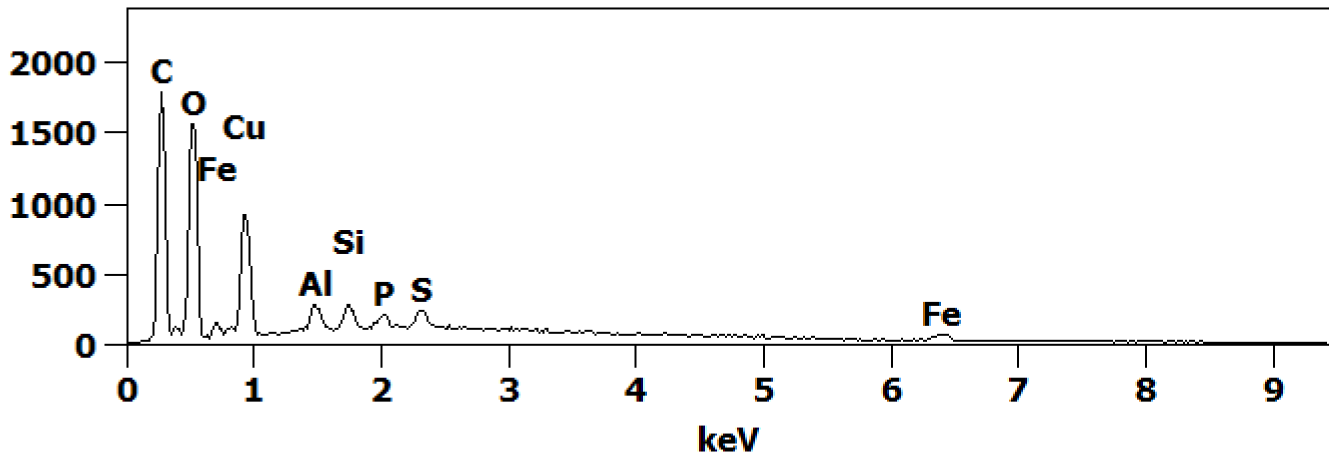
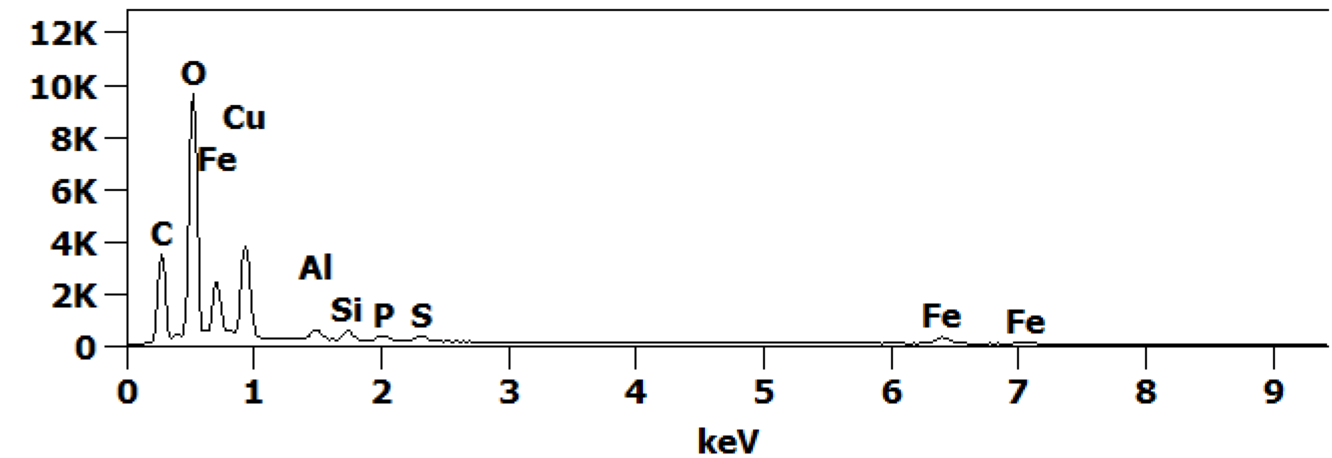


Image Name:	Oss G(1)
Image Resolution:	512 by 384
Image Pixel Size:	0.29 µm
Acc. Voltage:	10.0 kV
Magnification:	1415

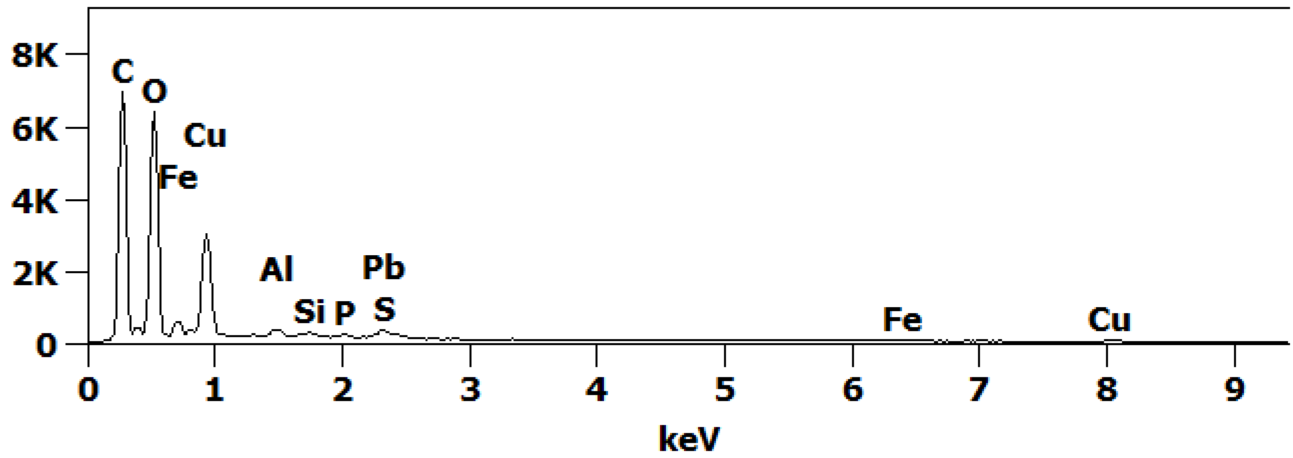
Full scale counts: 1779 **Oss G(1)_pt1**



Full scale counts: 9627 **Oss G(1)_pt2**



Full scale counts: 6938 **Oss G(1)_pt3**



Oss G(2)

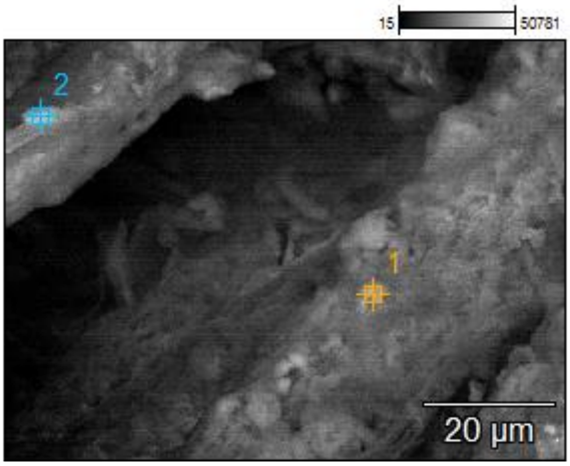
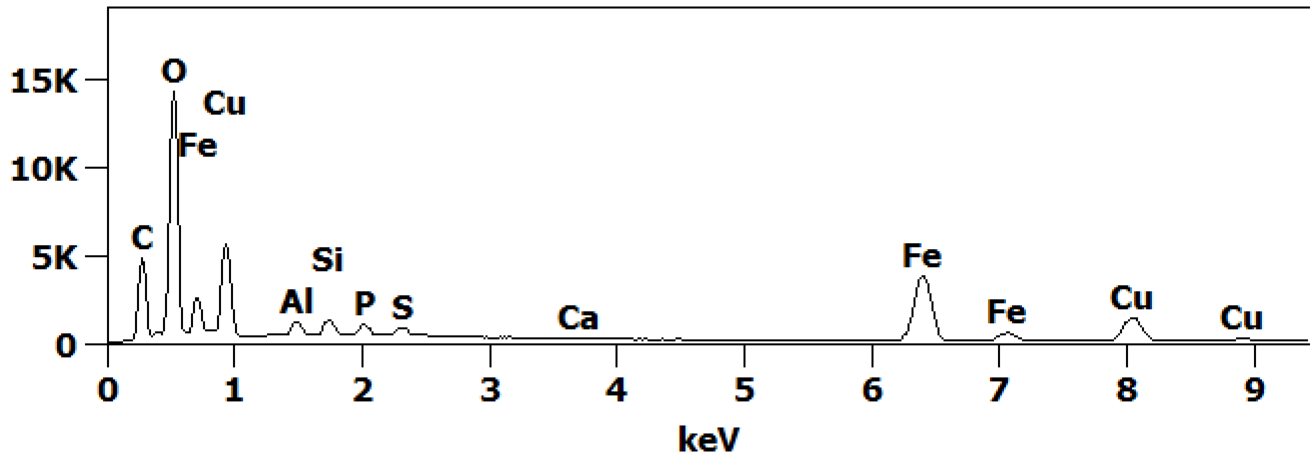
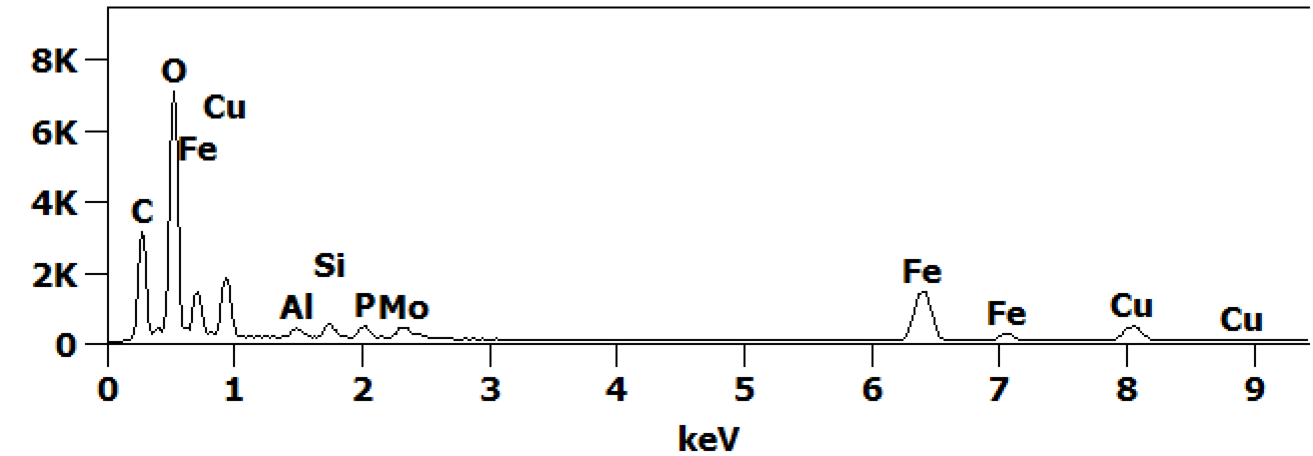


Image Name:	Oss G(2)
Image Resolution:	512 by 384
Image Pixel Size:	0.17 µm
Acc. Voltage:	20.0 kV
Magnification:	2445

Full scale counts: 14276 **Oss G(2)_pt1**



Full scale counts: 7078 **Oss G(2)_pt2**



Oss G(3)

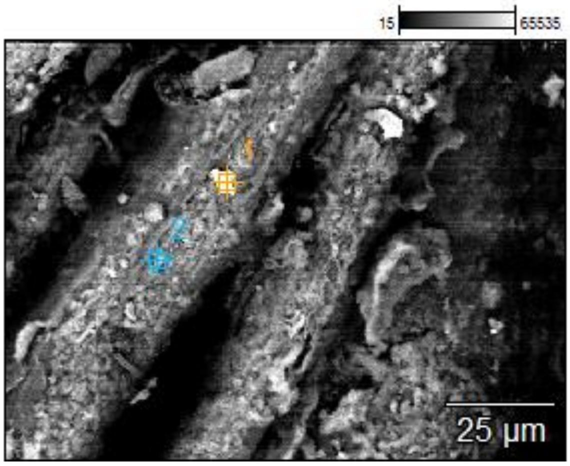
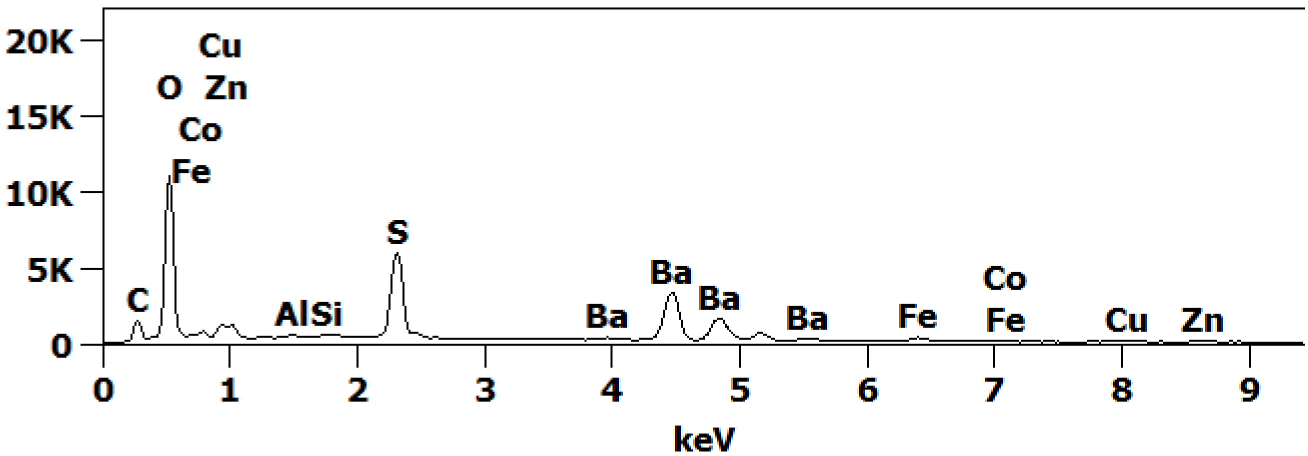
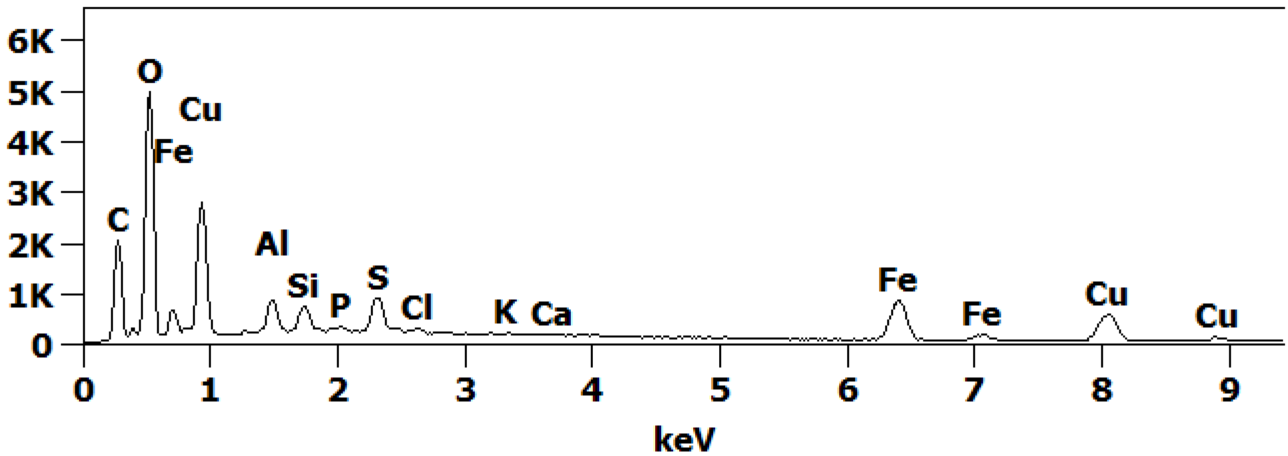


Image Name:	Oss G(3)
Image Resolution:	512 by 384
Image Pixel Size:	0.25 µm
Acc. Voltage:	15.0 kV
Magnification:	1630

Full scale counts: 10991 **Oss G(3)_pt1**



Full scale counts: 4965 **Oss G(3)_pt2**



Oss G(4)

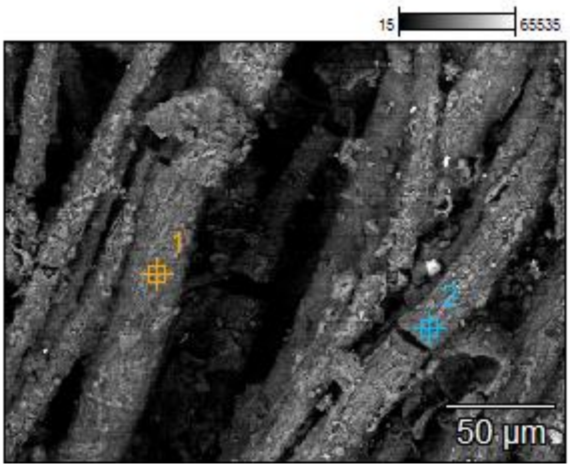
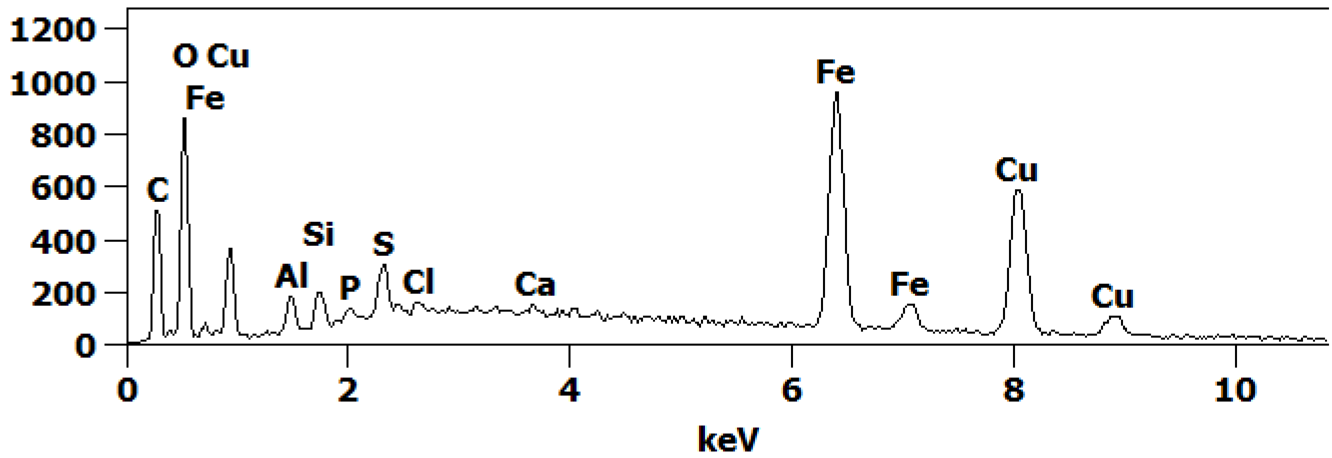
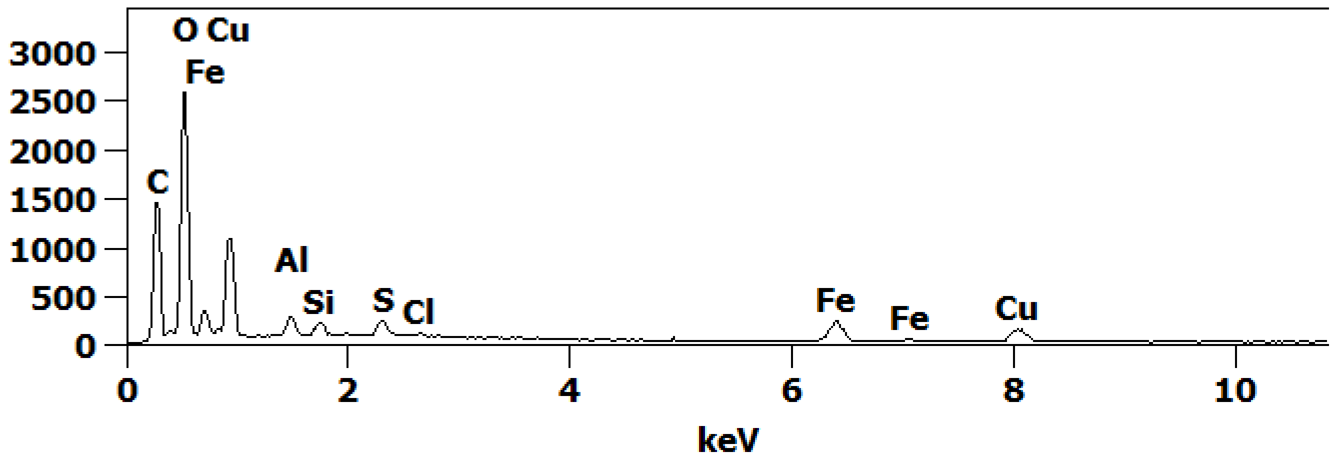


Image Name: Oss G(4)
Image Resolution: 512 by 384
Image Pixel Size: 0.50 µm
Acc. Voltage: 15.0 kV
Magnification: 815

Full scale counts: 956 **Oss G(4)_pt1**



Full scale counts: 2581 **Oss G(4)_pt2**



Oss G(5)

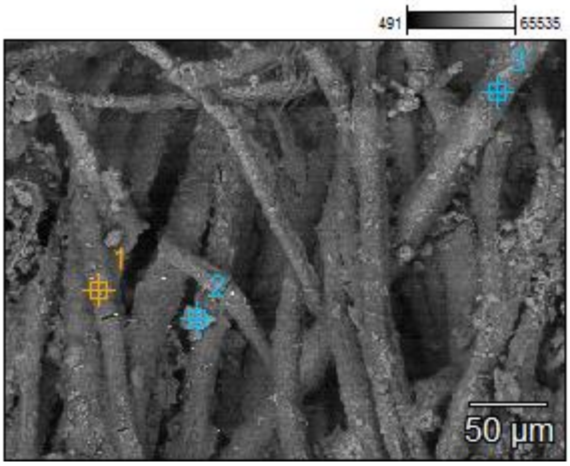
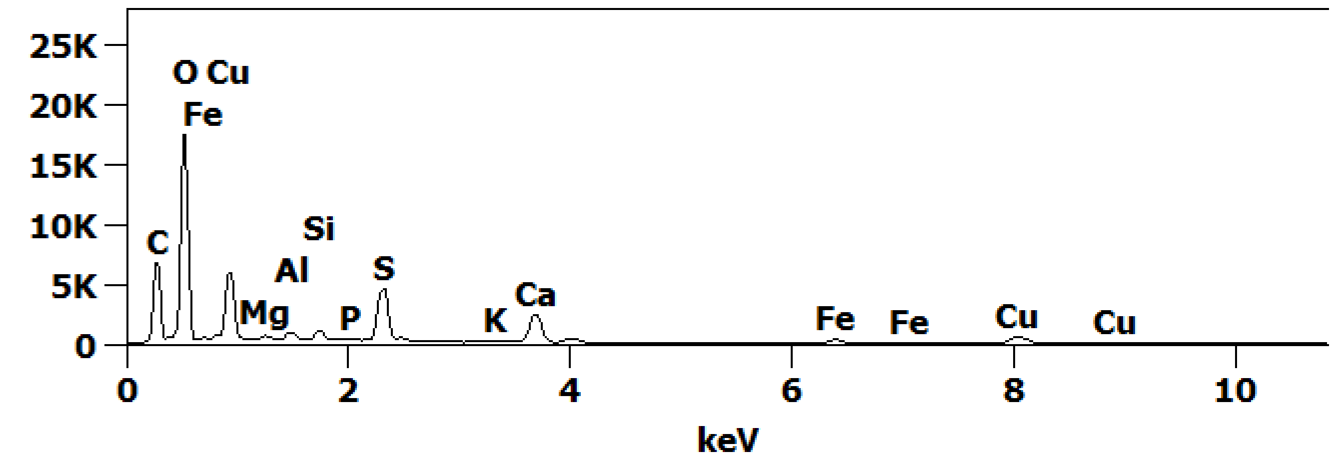
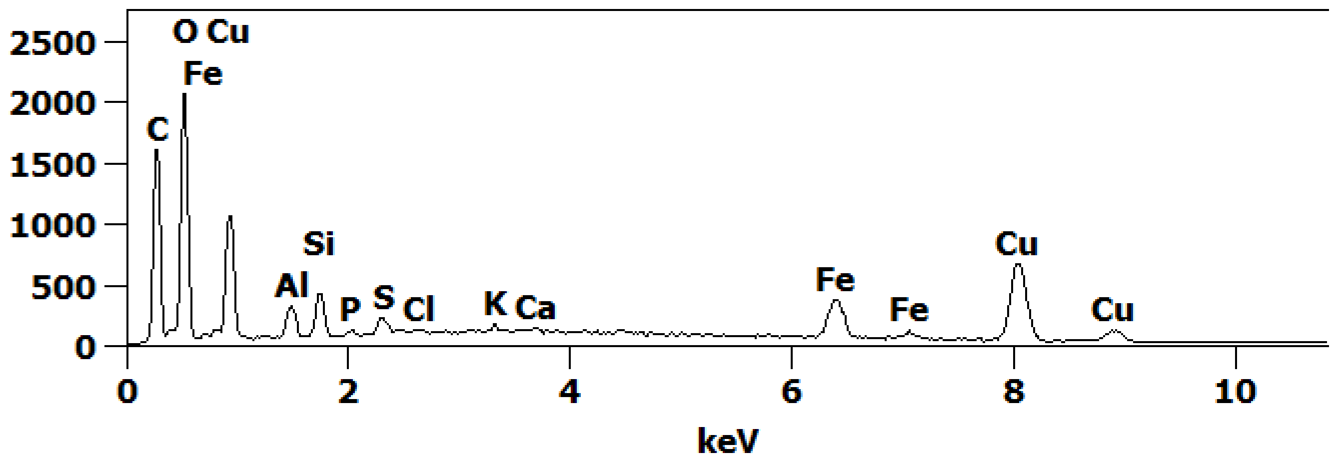


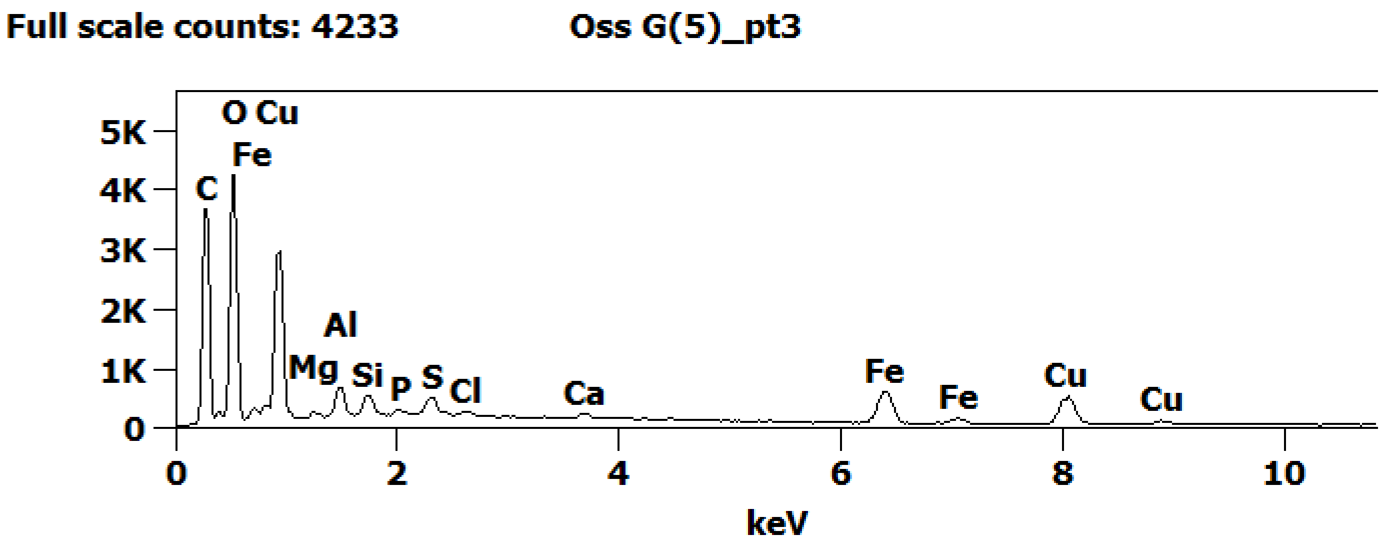
Image Name:	Oss G(5)
Image Resolution:	512 by 384
Image Pixel Size:	0.72 µm
Acc. Voltage:	15.0 kV
Magnification:	570

Full scale counts: 17417 **Oss G(5)_pt1**



Full scale counts: 2066 **Oss G(5)_pt2**





Full scale counts: 4233
Oss G(5)_pt3
5K
4K
3K
2K
1K
0
O Cu
Fe
C
Al
Mg
Si
P
S
Cl
Ca
Fe
Fe
Cu
Cu
0
2
4
6
8
10
keV

Oss G(6)

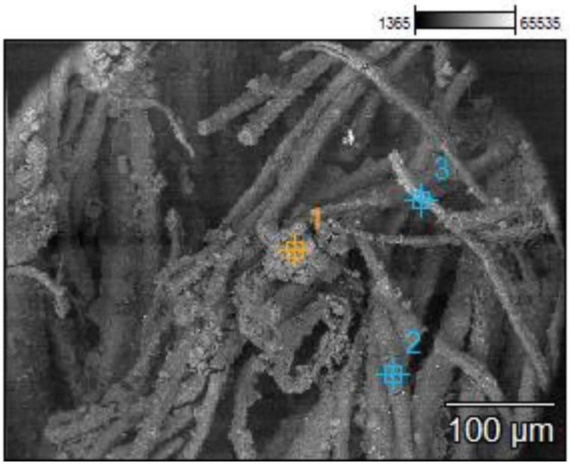
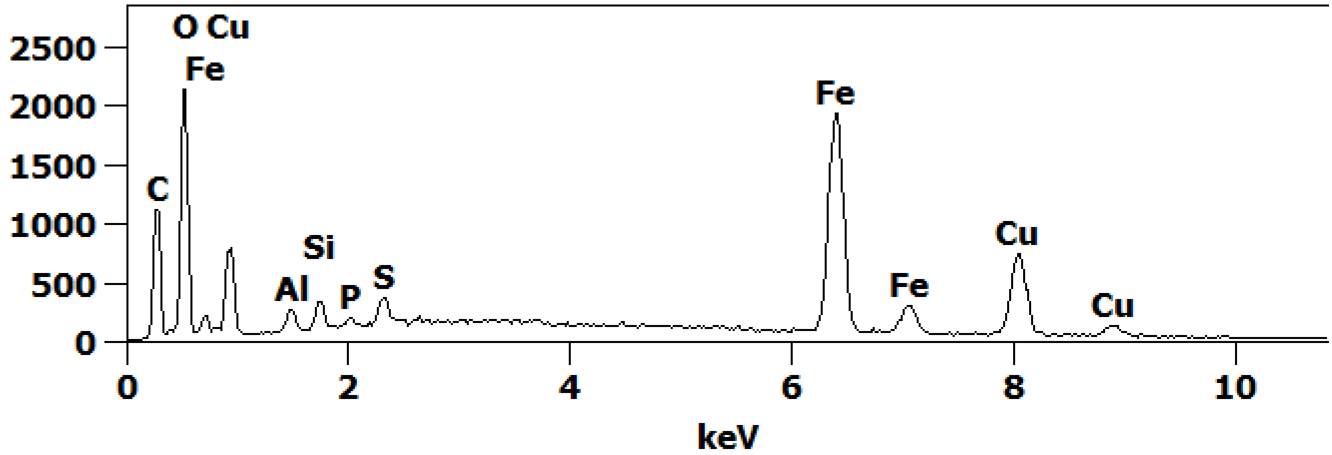
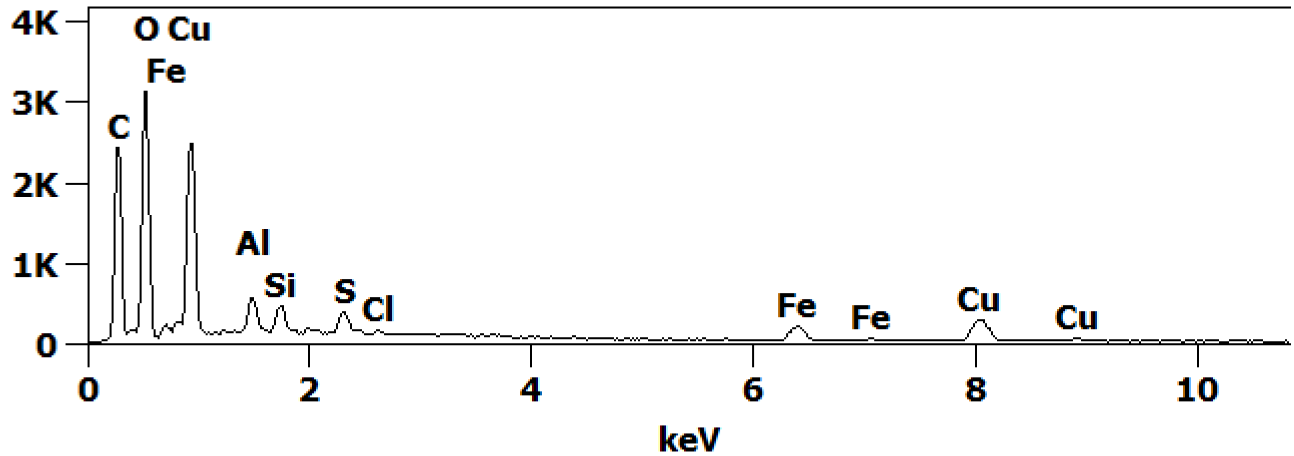


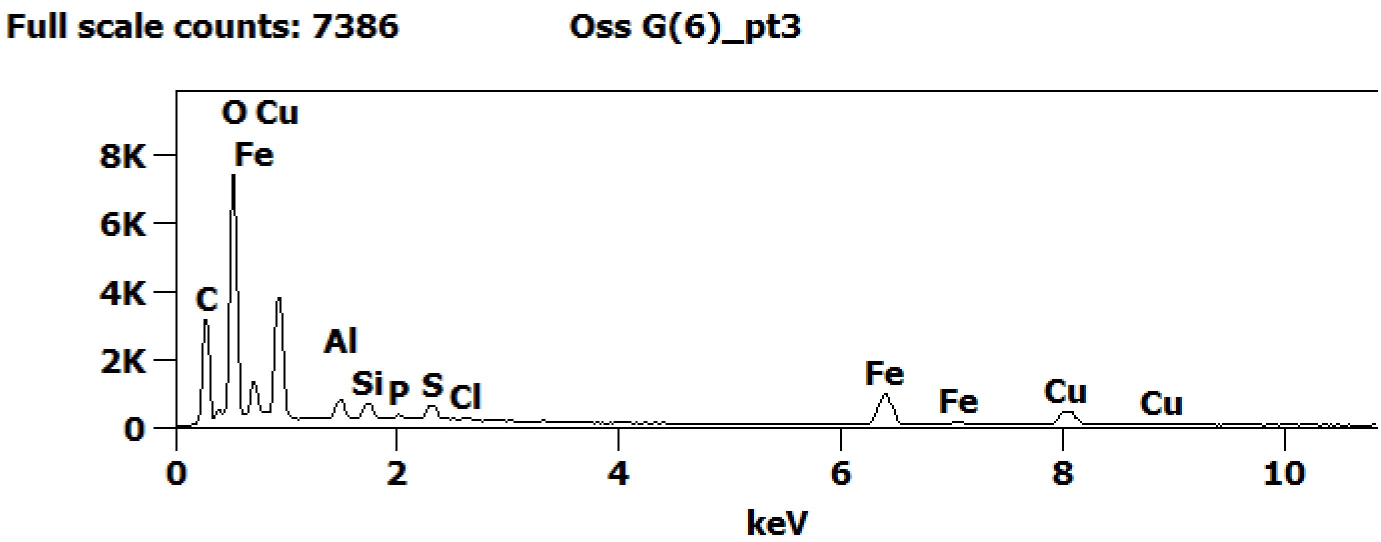
Image Name:	Oss G(6)
Image Resolution:	512 by 384
Image Pixel Size:	1.00 µm
Acc. Voltage:	15.0 kV
Magnification:	407

Full scale counts: 2132 **Oss G(6)_pt1**

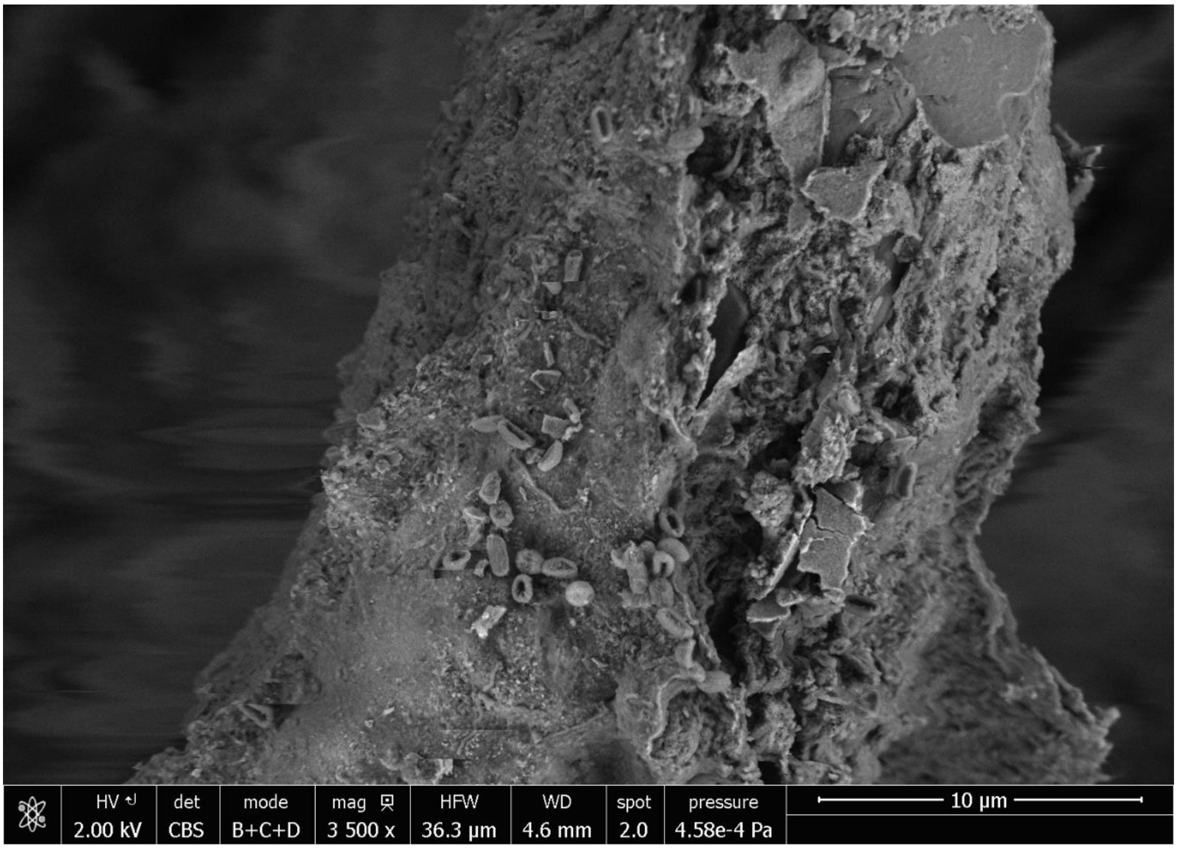


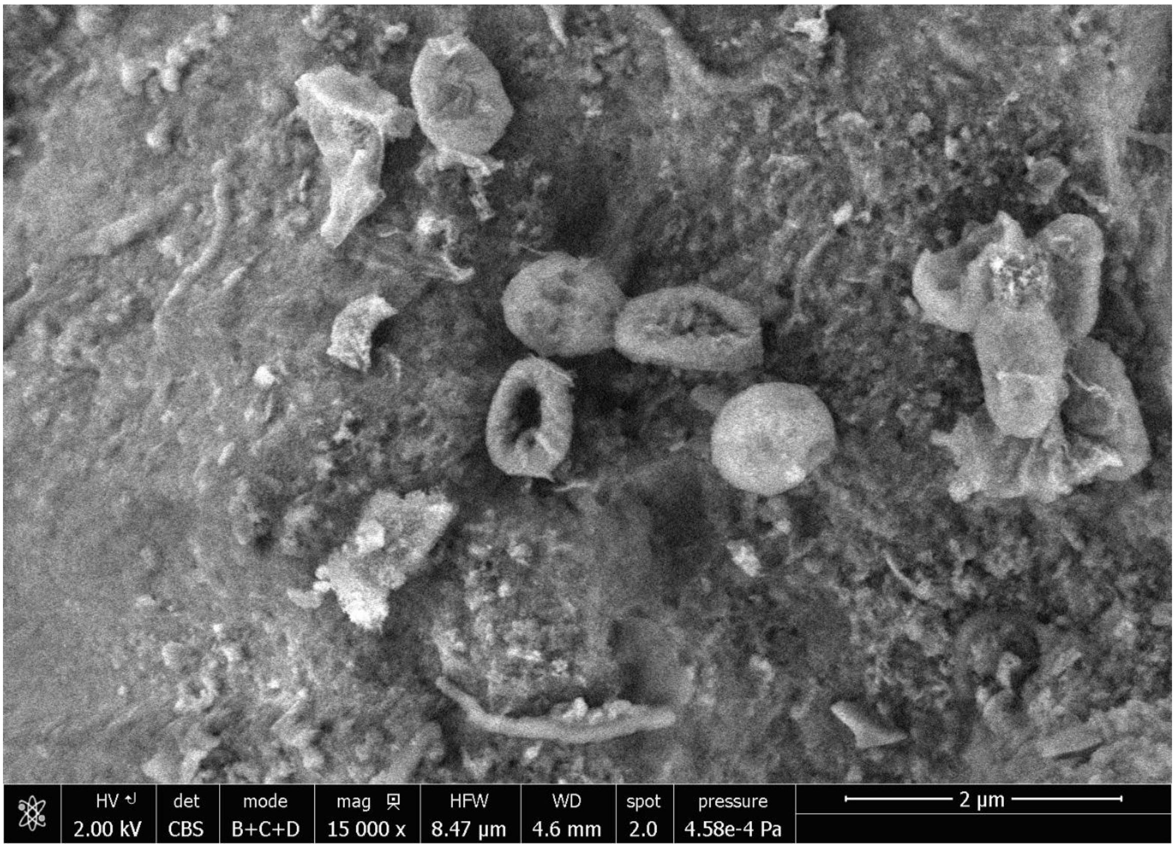
Full scale counts: 3124 **Oss G(6)_pt2**




Full scale counts: 7386
Oss G(6)_pt3
8K
6K
4K
2K
0
O Cu
Fe
C
Al
Si
P
S
Cl
Fe
Fe
Cu
Cu
0
2
4
6
8
10
keV

Appendix II: Close-up detail of donut shapes present in sample Oss-G (© Cultural Heritage Agency)





Appendix III: Chemical analysis of sample Slabroek 70A of Uden-Slabroekse Heide

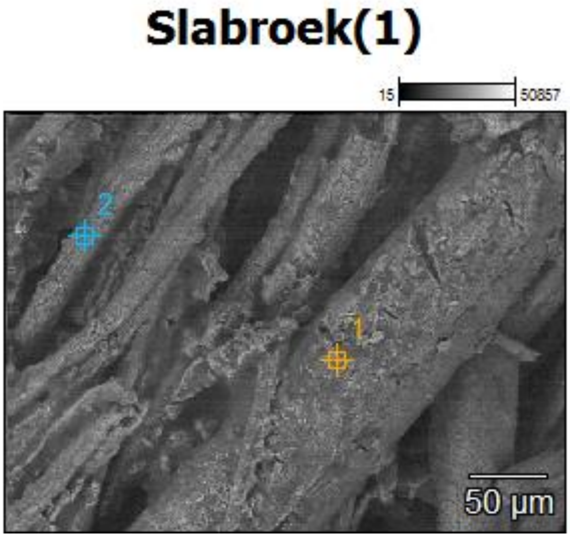
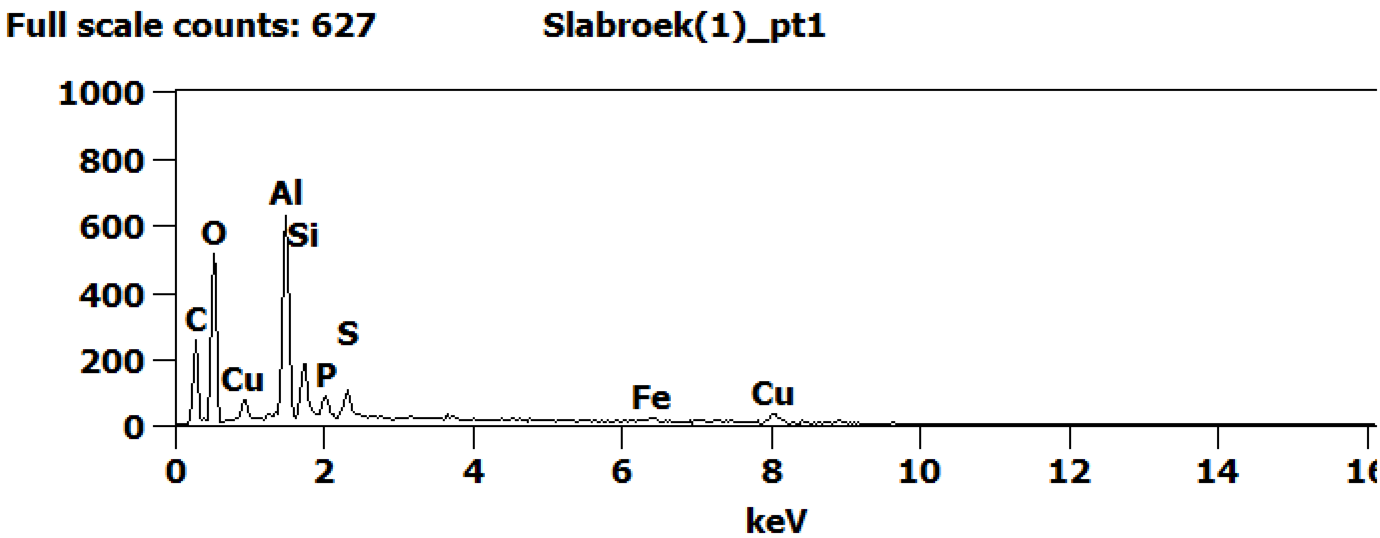
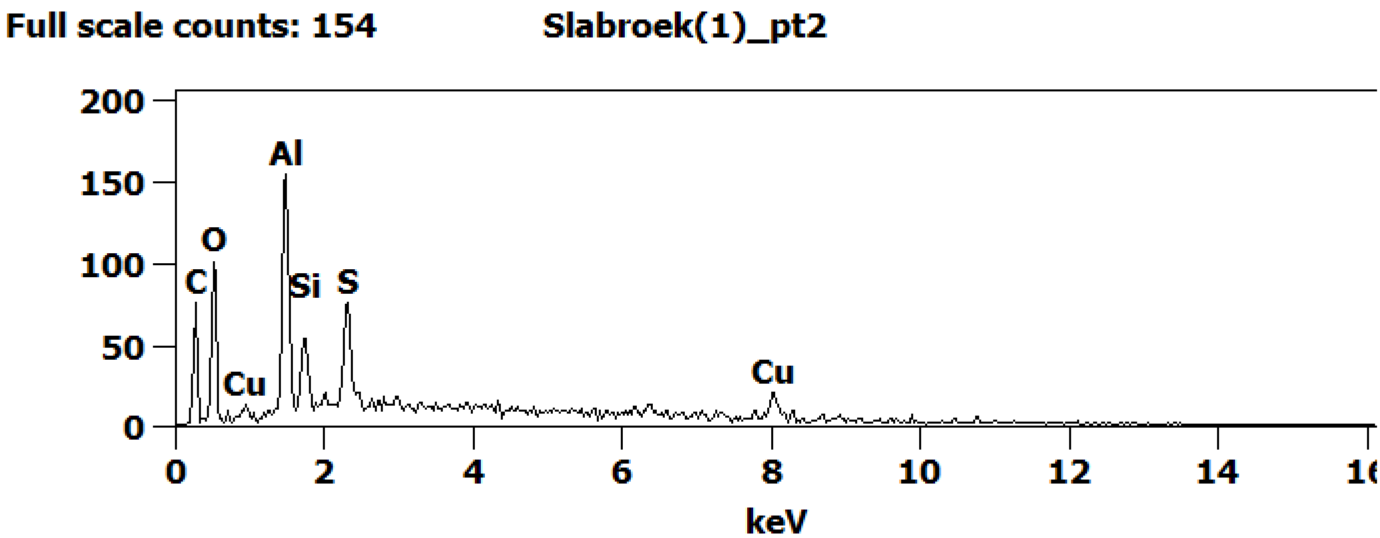


Image Name: Slabroek(1)
Image Resolution: 512 by 384
Image Pixel Size: 0.72 µm
Acc. Voltage: 15.0 kV
Magnification: 570





Slabroek(2)

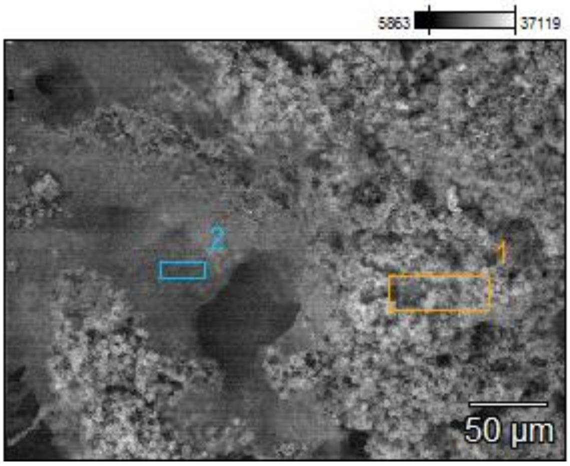
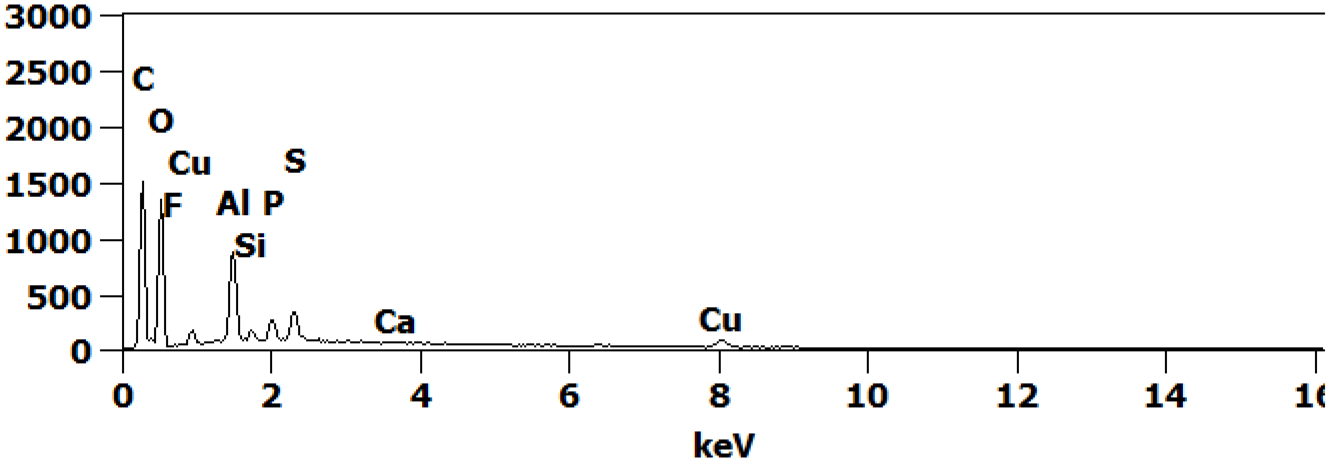
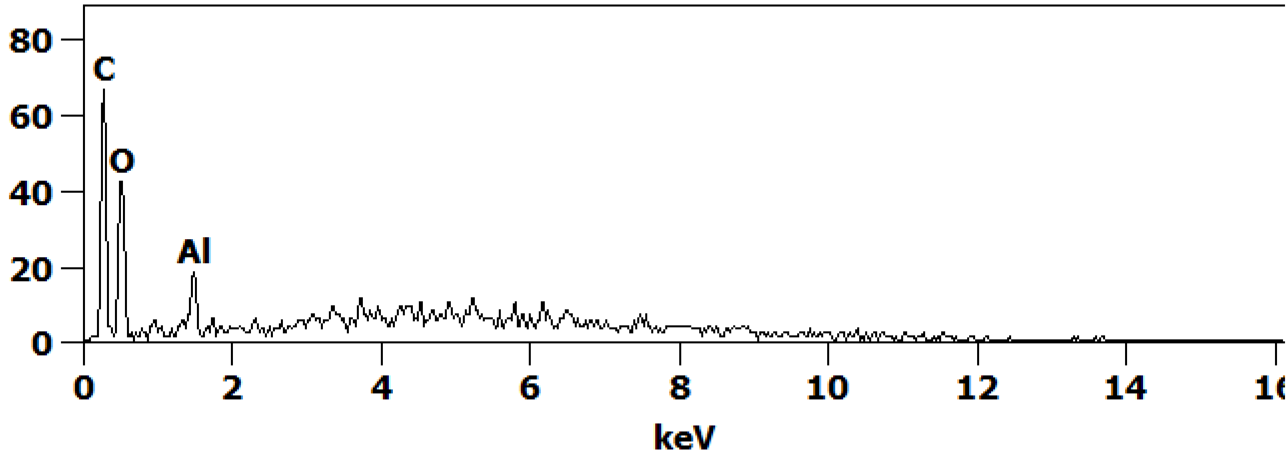


Image Name:	Slabroek(2)
Image Resolution:	512 by 384
Image Pixel Size:	0.72 µm
Acc. Voltage:	15.0 kV
Magnification:	570

Full scale counts: 1506 **Slabroek(2)_pt1**



Full scale counts: 67 **Slabroek(2)_pt2**



Slabroek(3)

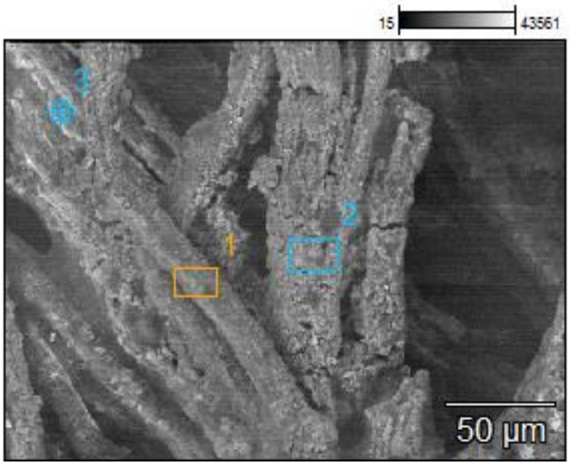
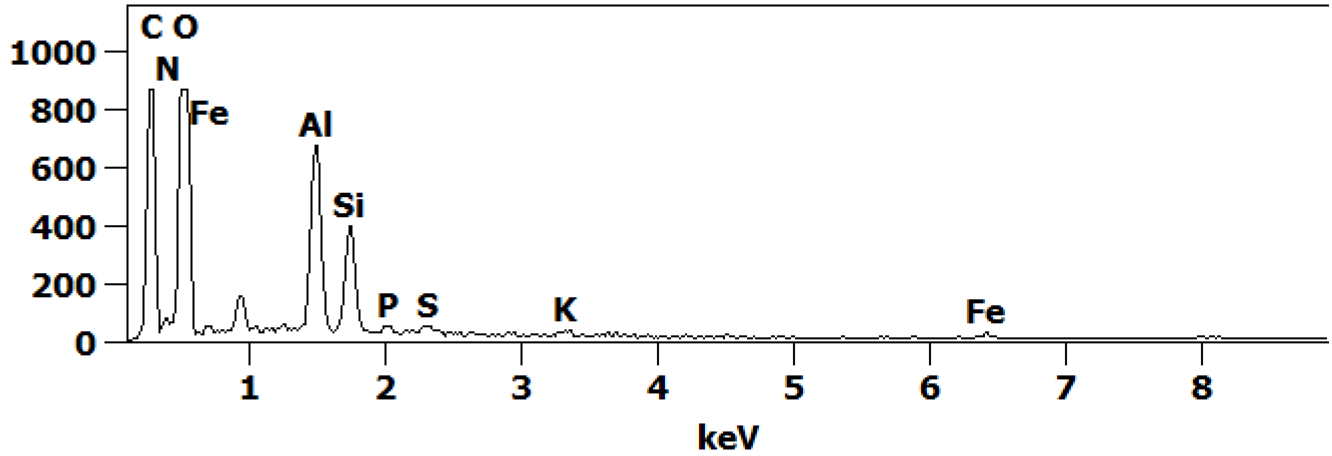
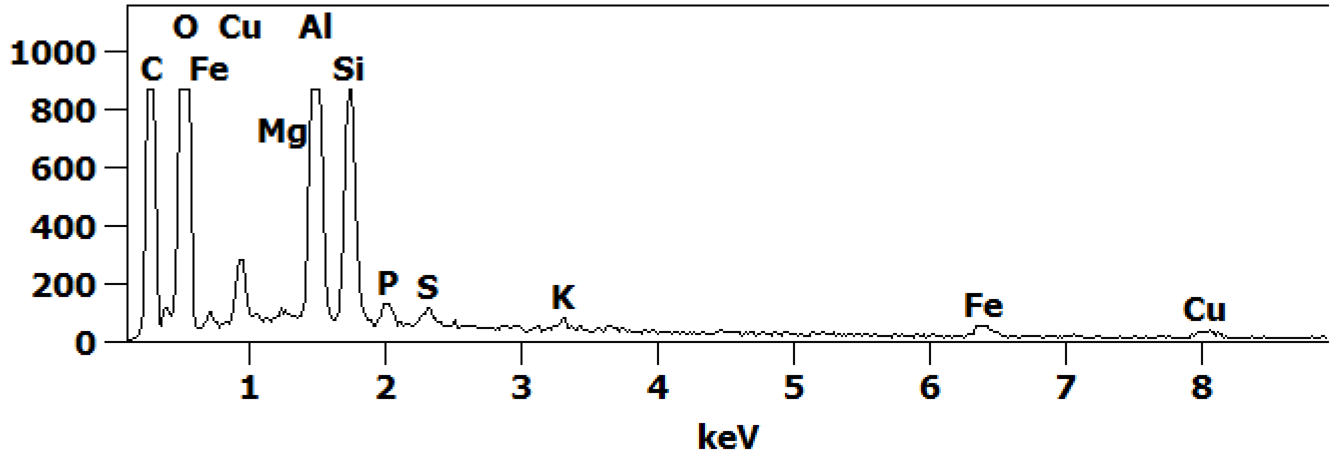


Image Name:	Slabroek(3)
Image Resolution:	512 by 384
Image Pixel Size:	0.50 µm
Acc. Voltage:	15.0 kV
Magnification:	815

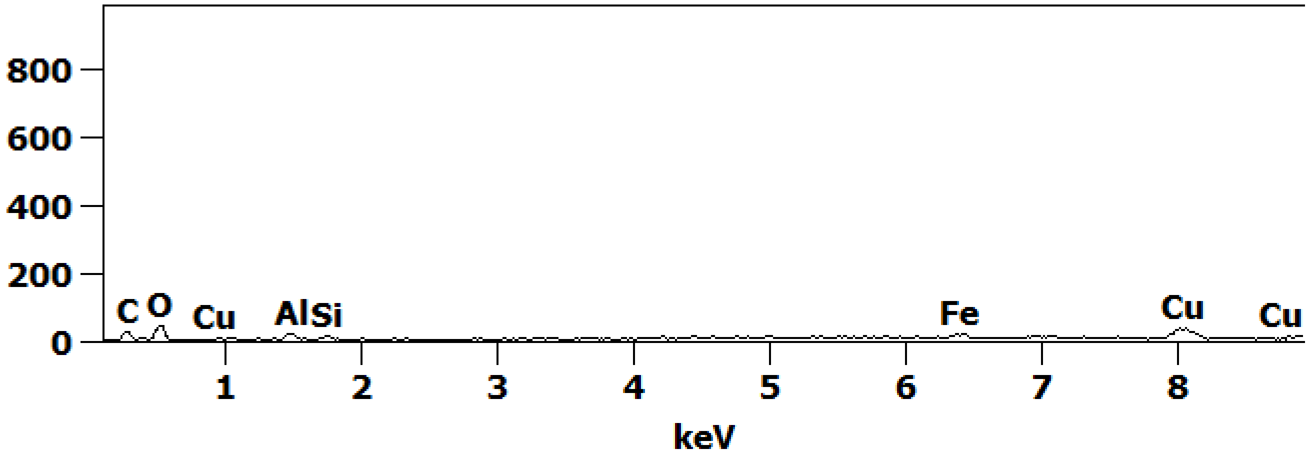
Full scale counts: 865 **Slabroek(3)_pt1**



Full scale counts: 865 **Slabroek(3)_pt2**



Full scale counts: 865 Slabroek(3)_pt3



Slabroek(4)

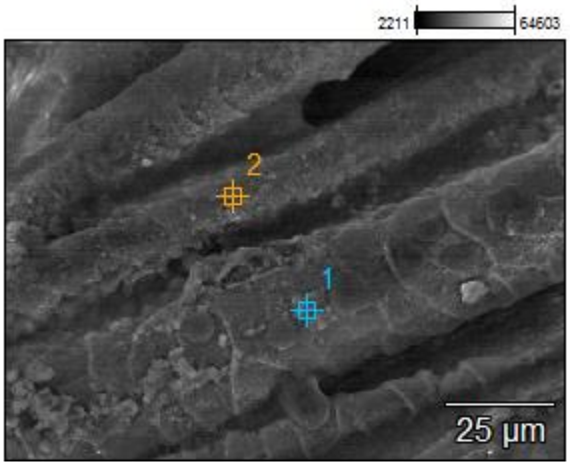
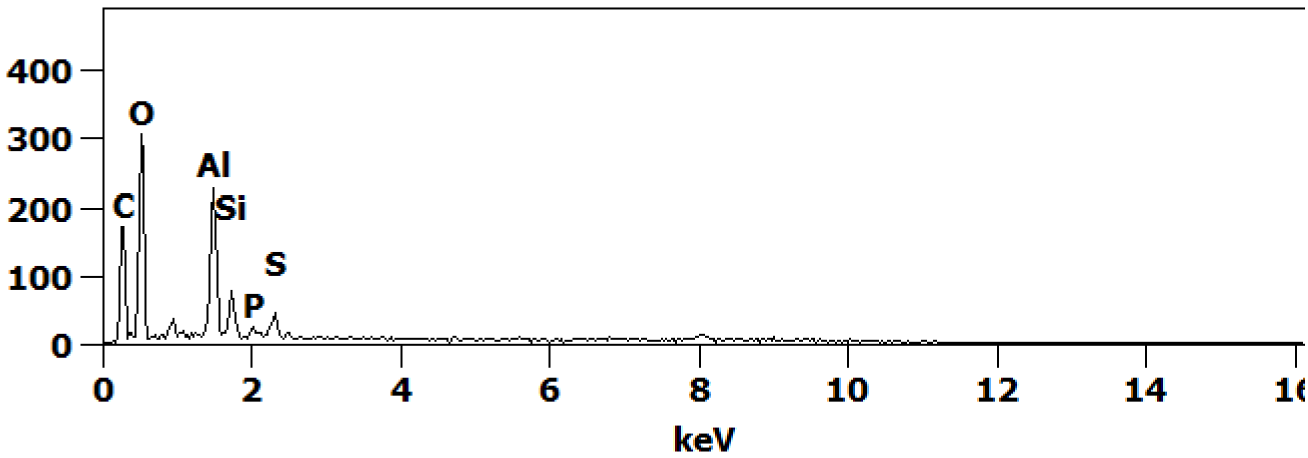


Image Name:	Slabroek(4)
Image Resolution:	512 by 384
Image Pixel Size:	0.25 µm
Acc. Voltage:	15.0 kV
Magnification:	1630

Full scale counts: 306 **Slabroek(4)_pt1**



Full scale counts: 281 **Slabroek(4)_pt2**