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Textiles burning: Understanding charred textiles from cremation graves through experimental charring

Karina Grömer, Margarita Gleba, Sophie Van Horne

Abstract

Traditionally, textile remains found in cremation graves are interpreted as subsequent wrapping, even if they are associated with burnt and deformed metal objects. Although this may often be the case, we want to postulate another possibility based on the results of experimental charring of textiles. Cremation experiments were carried out in an interdisciplinary cooperation between anthropologists, forensic scientists, and archaeologists in 2012, 2018, and 2019 in Asparn an der Zaya, Austria. A detailed documentation of the textiles before and after experimental cremation, as well as the burning conditions, permitted us to investigate the changes that the textiles underwent during the process. The textiles were analysed using Scanning Electron Microscopy (SEM). The results were compared with the data obtained from detailed textile charring tests carried out under controlled laboratory conditions at the University of Cambridge in 2018, which investigated the shrinkage of fibres, threads, and cloth in flax and wool textiles with respect to differences in temperature and exposure time .

Keywords: experimental archaeology, charring, textiles, controlled burning tests, SEM

26.1. Introduction: textile preservation through charring

Archaeological textiles survive thanks to a variety of natural and artificial environmental conditions (Figure 1). One of them is carbonization or charring. Charred textiles are well known from the Neolithic and Bronze Age circum-Alpine settlements (e.g. Bazzanella and Mayr 2009; Médard 2010; Rast-Eicher and Dietrich 2016) and the Late Bronze Age Must Farm settlement recently excavated in the UK (Harris and Gleba forthcoming paper). Less known are textiles from cremation burials, although examples have been recovered from various sites across Europe. For example, charred textiles have been found in British Bronze Age cremations, like the multi-layered fragments from the pit-pyre found under the Over Barrow 2 in Cambridgeshire, UK (Harris 2015). Charred textile fragments have also been recovered from several cremation sites in Spain: Carmona (Alfaro 1984; Alfaro and Tébar 2007), La Albufereta (Alfaro 1984; Verdú 2015: 417–418), El Ciggaralejo (Hundt 1968; Alfaro 1984: 119–121, 138–141), and El Turuñuelo (Marín-Aguilera et al. 2019) – the latter

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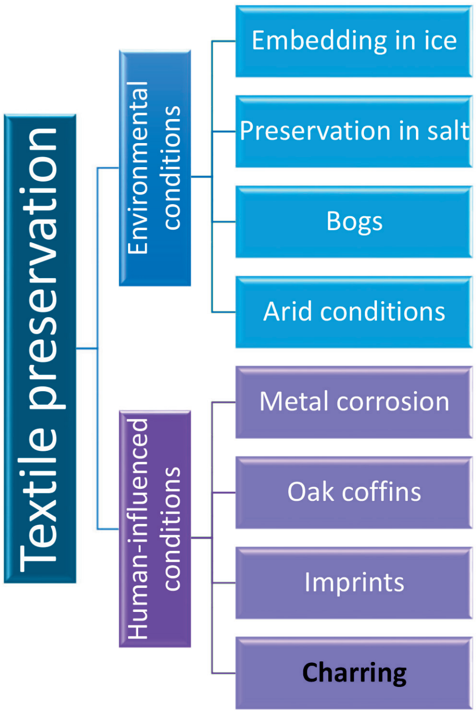


Figure 1. Modes of preservation, textiles from archaeological contexts. (Image: K. Grömer)

a result of a deliberate cremation of the entire site. In Greece, charred textiles were recovered from the pyre at Vergina (Moraitou 2007). In Italy, at Este, fragments were found during careful micro-excavations of cinerary urns (Maspero 1998, 64–67, 205–213; Ruta and Gleba 2018, 212–213). In Austria, a deformed burnt bracelet from a Late Bronze Age cremation grave preserves traces of textiles (Grömer 2014, Table 2), and an object from Mantrach, found in a Roman period cremation burial appears to have been attached to a fibula that was used to dress the corpse which was later burnt on the pyre (Grömer and Sedlmayer 2012: 162–164).

What were the conditions in which these fragments escaped the total destruction by fire and survived until today? What can they tell us about the original fabrics used by the past populations? In this paper we propose some approaches to answer these questions. Our data are based on two different and independent sets of cremation experiments. The first set includes cremation experiments carried out as an interdisciplinary cooperation between anthropologists, forensic scientists, cultural anthropologists, metallurgists, and archaeologists from the Museum of Natural History in Vienna and the University of Vienna in Asparn an der Zaya, Austria in 2012, 2018, and 2019. The second set involved charring raw wool, wool textile and linen textile in a laboratory at the University of Cambridge in 2018 under specific and controlled conditions. We describe both experiments, compare their results, and propose some observations that could be useful when dealing with charred textile remains from cremations. While these experiments do not address charred textiles from non-cremation contexts directly, they are relevant to all charred fabric remains.

26.2. Experimental cremations at Asparn an der Zaya

Four series of cremation experiments were carried out between 2012 and 2021. A late Bronze Age grave (ca. 1100 BCE) from Inzersdorf in Austria (Fritzl et al. 2019) served as a model for the metal and ceramic dress accessories and burial gifts. A pig was used as a substitute for the human body – fully dressed in a long-sleeved linen shirt, a head scarf and braids of hair, a wool cloak, a wool tablet-woven belt and a leather belt, covered with a linen shroud, and equipped with traditional costume elements (pins, belt buckle) (Figure 2b). The shroud was decorated with a total of 130 bronze buttons (Figure 3c) since numerous such buttons have been found in the grave at Inzersdorf. In order to achieve comparability, the cremation experiment was repeated four times, using the same sets of costume elements, garments, metal dress fittings, and burial goods produced for the purpose and set up the same way; only the size of the pig varied (as the animals selected for the experiment had died of natural causes rather than deliberately slaughtered).

The textile elements used in the experiment were first photographed individually and in groups. The pigs were hung on a pole for easier handling while dressing (Figure 3a). After placing the pig on the pyre, the bracelets were attached. The original position of the pig and all its accessories on the

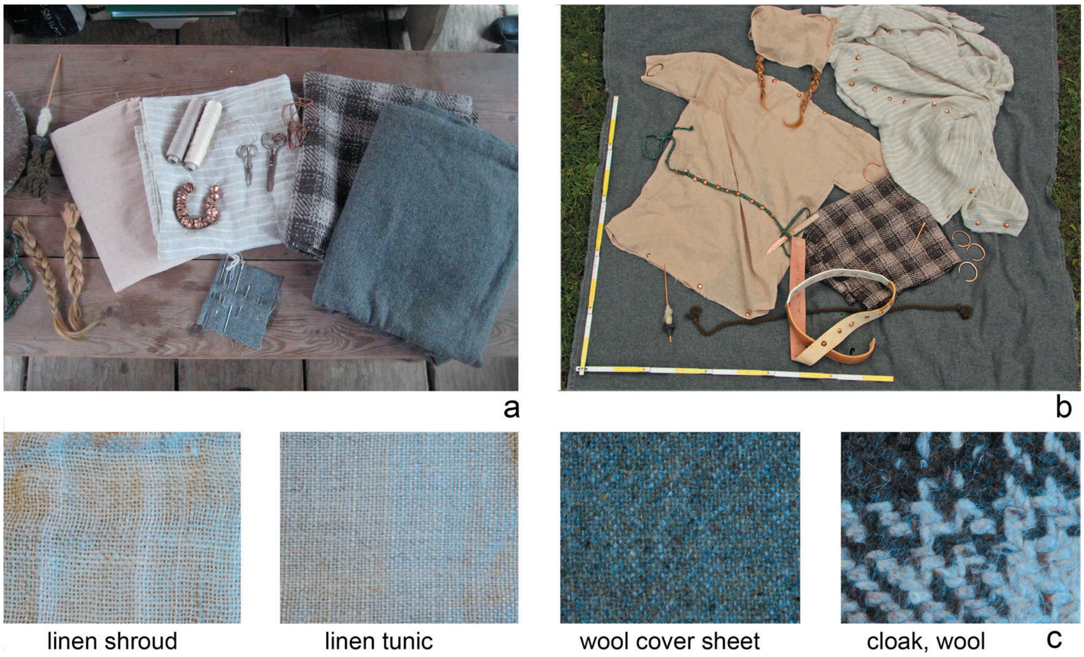


Figure 2. Setup of the cremation experiments: a and b) garment and metal dress accessories used; c) details of the fabrics. (Photographs: K. Grömer)

Figure 3. Cremation experiment sequence: a) dressing the pig; b) setting the pig on the pyre; c) pig covered with the shroud; d–e) pig on fire; f) burnt down cremation site. (Photographs: K. Grömer)

pyre was recorded in a scaled drawing in order to compare later the position of the metal and other elements after the pyre had burnt down.

The pyre was set on fire and started burning quickly, and was fully engulfed in flames after about five minutes. The temperatures of this uncontrolled, naturally burning fire reached an interior temperature (at the pig) of 900–1000 °C, while lower temperatures were measured around the edges (Fritzl et al. 2019; Figure 4). The burning process lasted about nine hours until the final stages were reached and only the ashes, cracked bones and deformed metal elements remained (Figure 3f). The *in situ* position of the remains after the pyre had burned were documented in a scaled drawing the following day.

26.2.1. Observations on the textiles during the cremation and documentation

After igniting (Figure 3d), one of the initial interesting observations was that the textiles did not start burning immediately. The shroud caught fire first; some textile parts near the pig's head fell down and no longer engulfed in flames. Although the pyre burned quickly, the pig's shroud lasted eight minutes. The bronze buttons originally attached on the wool mantle underneath the shroud sustained their placements even after the shroud had burned away. The wool mantle began to show blistered deformations on the surface after about 10 minutes.

After about 20 minutes, the outer layer of the wool mantle and the shirt underearth on the upper body of the pig had almost disappeared. Interestingly, however, at this point in time the head scarf tied around the skull was still almost entirely present, with the knot under the chin still intact after 30 minutes (Figure 4).

For the documentation on the following day, the cremation site was drawn at a 1:10 scale and all objects left after the fire (bronze elements, bones, ceramics) were documented using a grid as in an archaeological excavation. Surprisingly, more textile remains were recovered than expected (Figure 5).

During the recovery, an attempt was made to identify the original textiles based on their appearance (especially the fabric quality). This was later verified in the evaluation using microscope images and, in a few cases, had to be corrected. As already observed in the preliminary experiments, some textiles survived the fire when, at the beginning of the cremation process, parts of the shroud and the lining cloth fell off and were no longer exposed to the direct flames. They were charred, but left the fire before they were completely burned.

Figure 4. Cremation experiment 2019: Full burning phase after 30 min with parts of the linen scarf still visible (arrow). (Photograph: K. Grömer)

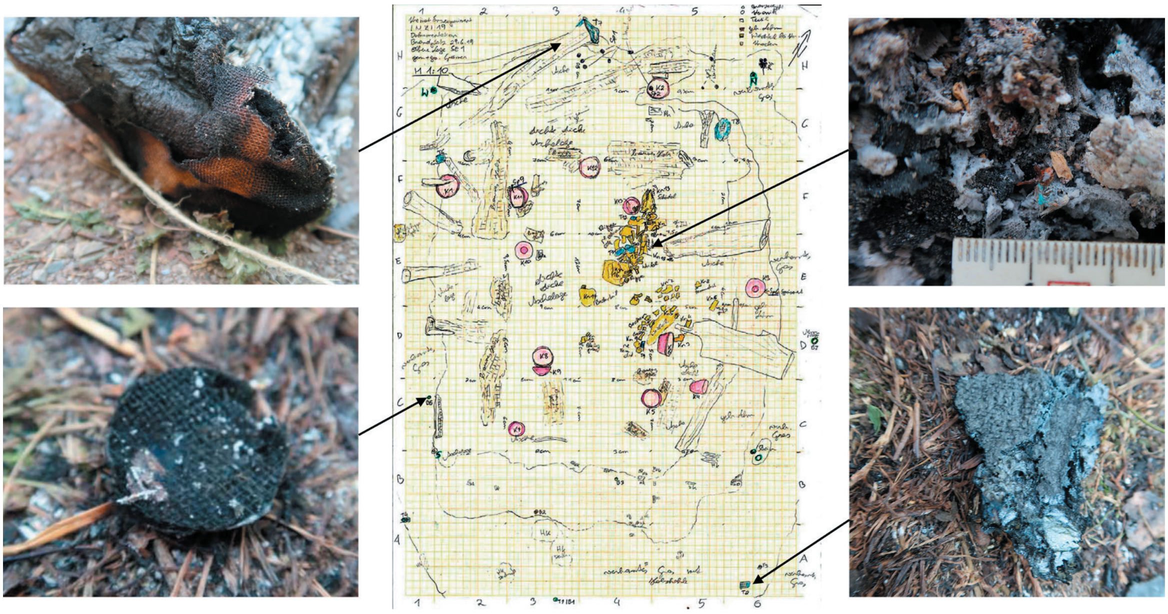


Figure 5. Example of the documentation of the pyre after it burnt down (experiment 2019) with some of the textile remains: a) wool cover sheet and linen shroud, b) linen tunic, c) linen shroud on a bronze buckle, d) linen shroud (Image: K. Grömer)

In each experiment setting, charred textiles that fell down from the pyre were documented after the burn was complete. Interestingly, charred textiles were also recovered from the central area of the cremation. Additionally, textile fragments were still adhering to bronze objects, such as the remains of the shroud on a bronze buckle in 2019 (Figure 5 left).

Macroscopic and microscopic examination of the textiles recovered from the experimental cremation was carried out following the usual textile analysis protocol (e.g. Walton and Eastwood 1989; Grömer 2014: 9–6) and compared to the original samples. The shrinkage of the textiles due to charring can be clearly observed (Figure 6). Due to shrinkage of the thread diameter, the fabrics appear much more open (especially in the case of the shroud). The shrinkage process is even more striking in the case of the wool cord, which shrank to half its original diameter (Figure 6b).

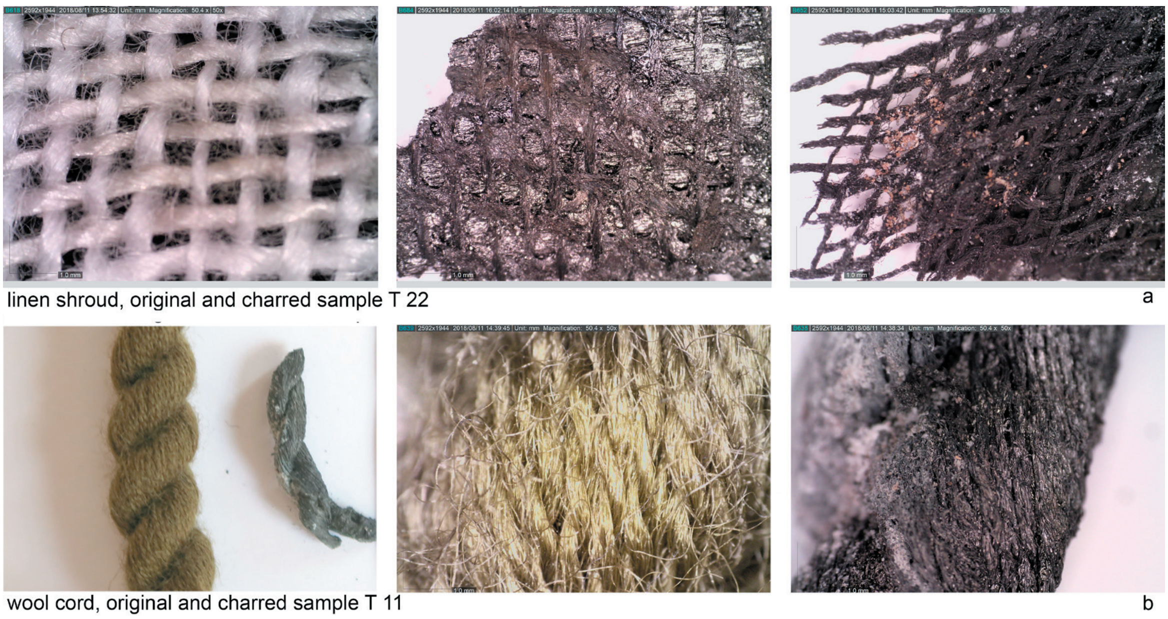


Figure 6. Comparison of the textiles before and after the cremation (Experiment 2018): a) linen shroud (sample T22a); b) wool cord (sample T11) (Photographs: K. Grömer)

26.3. Experiments at Cambridge

A different set of experiments were carried out as part of MPhil dissertation by Sophie Van Horne at the University of Cambridge in 2018. They examined the processes and effects of textile charring under controlled laboratory conditions (a full publication of the results is forthcoming).

The project aimed to answer the following questions: How can we reproduce authentic charring conditions? And how can we experimentally recreate charred wool and linen textiles? If we can do this successfully, how can these experimental results help our interpretation of actual charred archaeological samples? Specifically, the experiments investigated the following:

1. at what temperatures charring occurs in wool and flax, which are chemically and physically different, as this can help understanding the context of their survival (or non-survival);
2. what are the chemical changes that fibres undergo during charring;
3. what physical changes occur in textiles during charring (e.g. is there a set percentage of fibre diameters shrinkage after charring?).

Our hope was that by answering these questions, we can 'reverse-engineer' the charred textiles we find in archaeological contexts.

Since wool and flax were the principal materials used by prehistoric European populations, we focused our experiments on these two fibres. In order to replicate the original conditions as much as possible and to minimise additional chemical variables during testing, we sourced organically grown wool and linen fibres. The undyed linen (*Linum usitatissimum*), sourced from Libeco Belgian Linen, was organically grown then mechanically spun and woven into a tabby textile. The wool, also undyed, was sourced from a Texel cross sheep from a local breeder and the underwool from the fleece was used as the material for the unwashed wool, washed wool, and wool textile samples, the latter hand-spun and hand-woven into a 2/2 diagonal twill by local craftswomen.

Experimental charring was performed in the Department of Geography's Science Laboratories using a Carbolite ELF chamber furnace. Charring runs included four durations of exposure: one hour, two hours, three hours, and four hours at different temperatures (100, 200, 300, 400, 500 and 600 ˚C). Samples were double-wrapped in aluminium foil and placed within a dehydrated sand matrix to exclude as much oxygen as possible around the sample during charring.

The methodology for analysing the experimental samples employed two main techniques: Scanning Electron Microscopy (SEM) analysis was used to compare pre- and post-charring samples across a variety of measurements, including average fibre diameter, thread diameter and deformation or shrinkage in woven samples. Fourier Transform Infrared Spectroscopy (FTIR) analysis was used to examine chemical changes in the experimental material before and after charring in order to see if a pattern can be determined in conjunction with data from SEM analysis.

The main results of these controlled experiments are as follows:

- Wool does not preserve structurally above 200 °C, turning into a liquefied and re-solidified charred material by 300 °C. Wool samples become relatively brittle at 200 °C, especially longer than 2 hours of exposure and are extremely non-cohesive once fibre structure is lost.
- The results of the wool quality analysis indicate that wool textiles may not show change in fibre classification after charring.
- Linen preserves structurally through 600 °C. We tested linen at 800 and 1000 °C as well, but these results are still being analysed. The textiles did survive at 1000 °C however, shrank more than three times and turned bone-white in colour.

- Fully charred linen is relatively brittle and can be destroyed by external physical forces (burial, compression, bioturbation).
- The loss of mass analysis shows that linen and wool lose mass in predictable ways based on conditions, indicating it may be possible to reconstruct the original weight and volume of charred archaeological finds if charring temperature and time can be known through chemical or physical analysis.
- Statistical thread and fibre diameter analyses for linen indicate the primary importance of temperature on linen fibre shrinkage after charring.
- FTIR can be used to distinguish between materials and between charring temperatures (through 600 °C) for wool and linen textile, while charring time was less impactful, even at low temperatures (200 °C).

26.4. Other charring experiments

Recently, Christina Margariti (2020) obtained similar results to those of the Cambridge experiments by carbonising textiles made of cellulosic (cotton, flax, hemp, nettle) and proteinaceous (silk, wool) in a limited oxygen environment at 250, 350, and 500 °C for one hour. Wool and silk samples were destroyed at temperatures above 250 °C. All cellulosic and silk samples shrank, and their weight was reduced at different percentages depending on the material; these percentages increased as the temperature increased. Exceptionally, wool textile samples exhibited extreme shrinkage but also an increase in their weight. Similarly, the fibre diameters of cellulosic and silk fibres did shrank gradually at different degrees when the temperature increased. As a result of artificial carbonisation, the characteristic features of the fibres survived, as long as the material itself was preserved.

Daniel Istrate and colleagues (2016) investigated hair fibres by heating them in a nitrogen atmosphere. Irreversible thermal denaturation of keratin fibres and the pyrolysis of the fibres were observed at around around 240 °C. At temperatures beyond 230°C the fibres' cortex disappeared and the original modulated fibres converted into micro-tubes, consisting of only cuticles. These tubes become brittle, and disintegrated at around 300 °C (Istrate et al. 2016: 593). While no micro-tubing was observed in the Cambridge or in Margariti's experiments, the phenomenon has been documented in the charred textiles from Pompeii, suggesting that special conditions were created during the Vesuvian eruption which caused their charring (pers. comm. Francesca Coletti).

These studies thus corroborate the results of the Cambridge experiments which show that wool is unlikely to survive above 300 °C unless under very special conditions. In contrast, plant fibres can survive in much higher temperatures, although they shrink significantly.

26.5. Using Cambridge controlled charring results to interpret Asparn cremation experiments

How can Cambridge and other controlled charring experiments be used to interpret the results of the Asparn cremation experiments? Five charred textile samples from the 2018 experiment were analysed using Hitachi SU 5000 SEM at the Ludwig Maximilian University of Munich, Germany, and compared with the original, uncharred samples. In all cases the thread count increased dramatically, while the thread diameter decreased by 58–78 % (Figure 7a and 7b; Table 1). The latter change is higher than the shrinkage observed for linen threads in Cambridge experiments at 600 ˚C, suggesting that the temperature at which the fragments underwent charring was higher. Considering that the

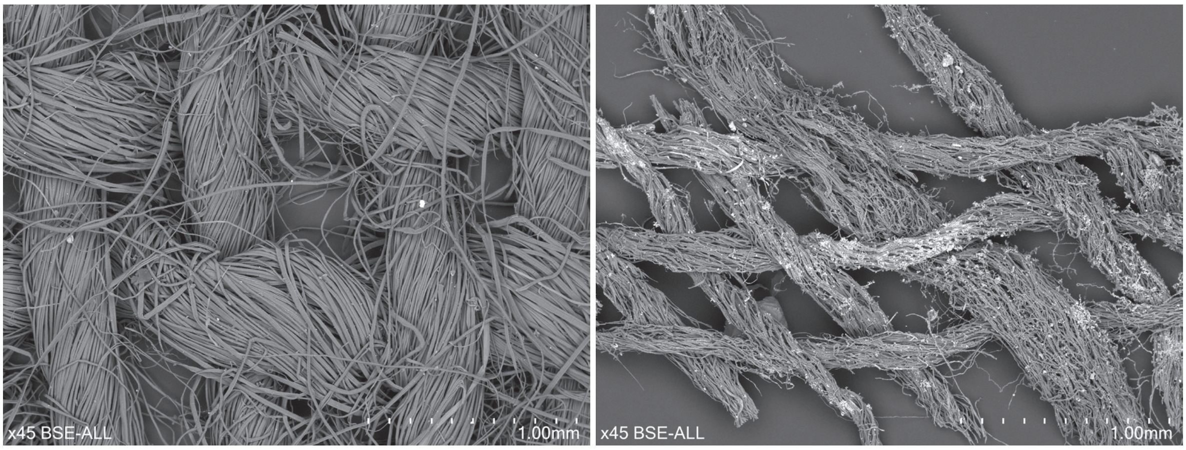


Figure 7. SEM micrographs of original (left) and charred (right) sample T22a at the same magnification (Images: M. Gleba)

Table 1. Results of thread analysis in original and charred samples from Asparn experiments. In charred samples, thread counts were calculated due to the small size of the samples.

Sample	Material	Weave	Thread count (cm)	Thread diameter (mm) (range in brackets)	Thread count decrease (%)	Shrinkage of thread (%)
T4 original Wool cover sheet	wool	z/z tabby	8/8	0.6–0.7/ 0.7		
T4 charred	?	z/z tabby	30/25	0.16 (0.11–0.19)/ 0.15 (0.11–0.24)	73/68	75/78
T14 original Wool mantle	wool	z/z twill	4-5/4.5	2–2.2/ 2–2.2		
T 14 charred	-	-	-	-	-	-
T19 original Linen tunic	linen	z/z tabby	16/14-16	0.47 (0.3–0.6)/ 0.5 (0.4–0.7)		
T19 charred	plant bast	z/z tabby	40/25	0.14 (0.1–0.18)/ 0.2 (0.12–0.3)	60/40	70/60
T22a original Linen shroud	linen	z/z tabby	15/12	0.37 (0.3–0.8)/ 0.51 (0.4–0.8)		
T22a charred	plant bast	z/z tabby	26/20	0.16 (0.11–0.21)/ 0.21 (0.1–0.4)	42/40	62/58
T23 charred (assumed to be same as T19 at recovery but more likely T4)	?	z/z tabby	30/25	0.15 (0.1–0.18)/ 0.19 (0.12–0.25)	?	?

Table 2. Results of fibre diameter analysis in original and charred samples from Asparn experiments.

Sample	Material	Count of fibres	Mean (µ)	Median (µ)	Mode (µ)	Range (µ)	Mean of shrinkage (%)
T19 original	linen	215	14	13.3	11.9	3.9–26.7, 29.3–32.4, 38.5	
T19 charred	linen	214	3.8	3.5	3.2	1–9.8	73
T22a original	linen	130	15.4	14.4	16.8	4.6–32.3, 39.4	
T22a charred	linen	108	4.1	3.9	3.3	1.2–8.8	73

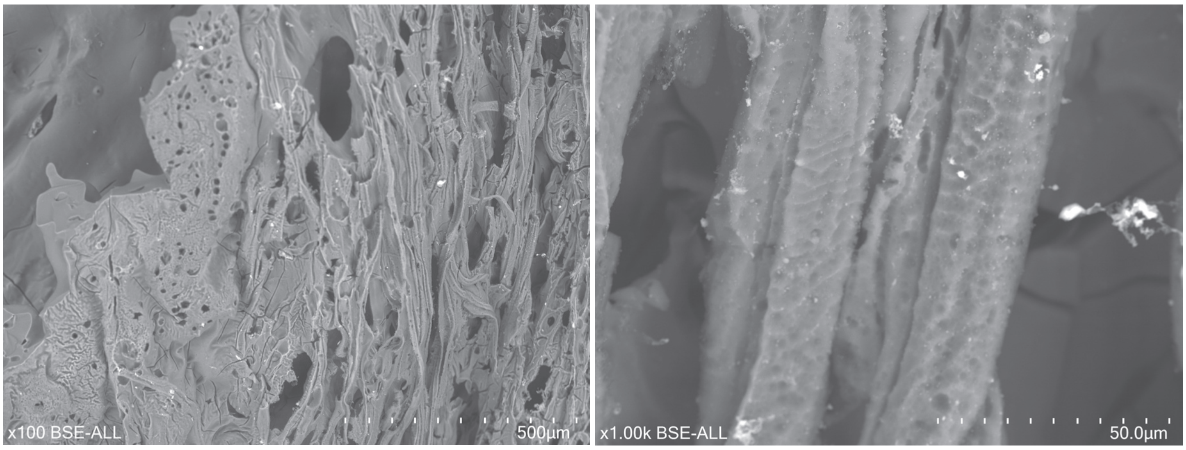


Figure 8. SEM micrograph of T11 with 'melted appearance', with some fibres preserved cuticular scales indicative of wool. (Images: M. Gleba)

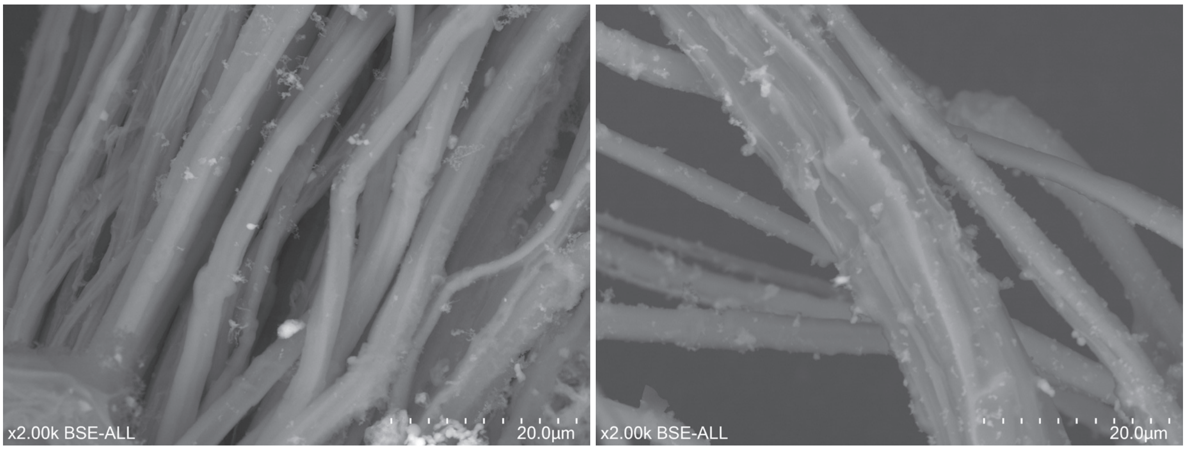


Figure 9. SEM micrographs of plant bast fibres with characteristic features in samples T19 (left) and T22a (right). (Images: M. Gleba)

pyre temperature reached 1000 °C, it is likely that the data will be comparable to the Cambridge experiments conducted above 600 °C.

Looking at the fibre level, there are substantial differences in the preservation of wool and linen textiles. Although in one of the charred wool samples (T11 – "Wollkordel"), the cuticular scales are still discernible on the surface of some fibres, overall the fibres present a 'melted' appearance (Figure 8), making fibre diameter measurement and therefore comparison with the original sample impossible.

In contrast, flax fibres remained relatively distinct and identifiable as plant bast fibres, with nodes/dislocations clearly visible (Figure 9), although their diameters reduced significantly. The fibre diameters in linen charred samples could be measured and compared with the original materials. In samples T19 (linen tunic) and T22a (linen shroud), a significant reduction in both the diameter and the range of diameters is observed, as demonstrated by the corresponding histograms (Table 2; Figures 10a–d). The mean shrinkage is about 73%. This is again higher than the shrinkage observed for linen threads in the Cambridge experiments at 600 °C, suggesting that the temperature at which the fragments underwent charring was higher.

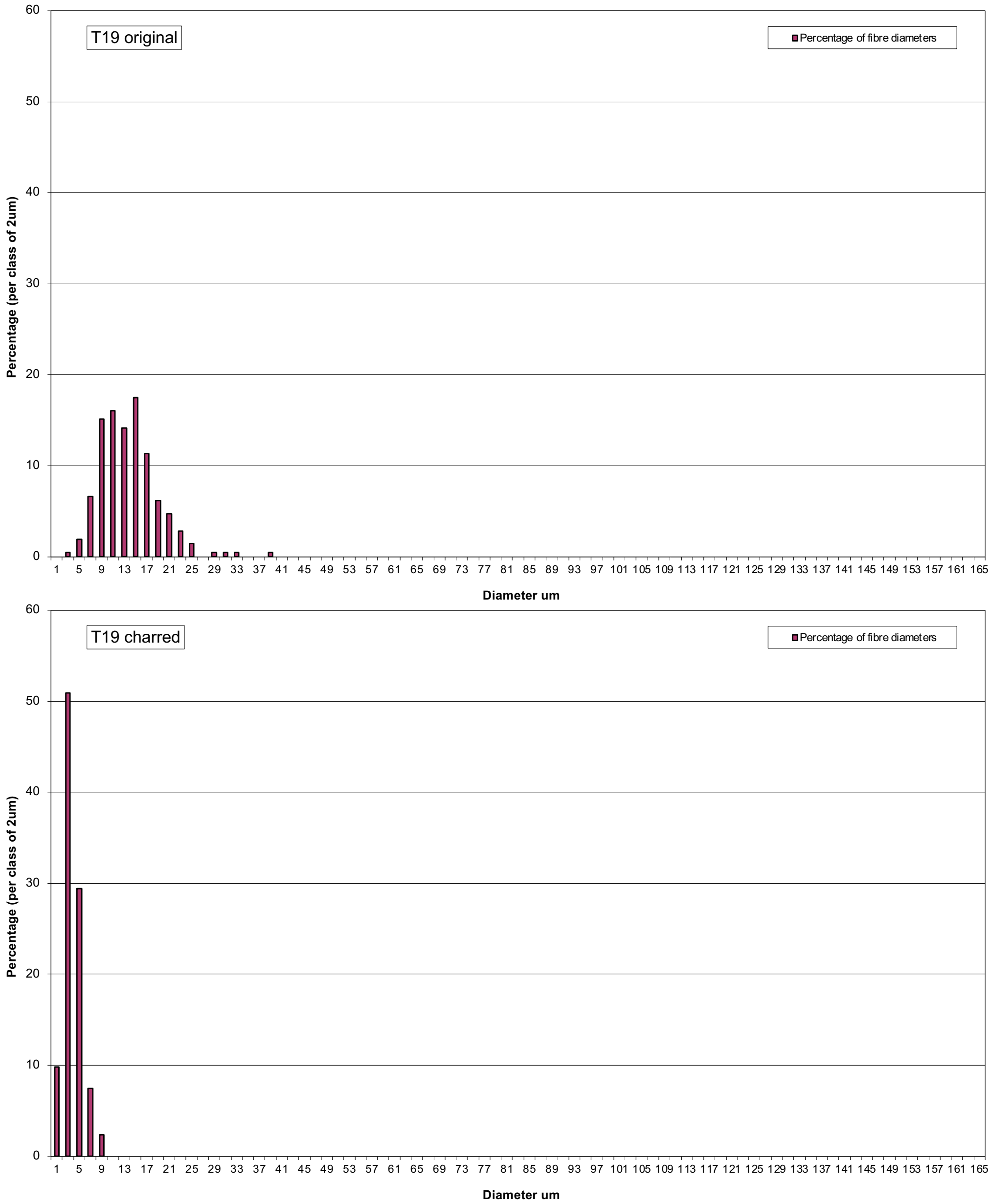
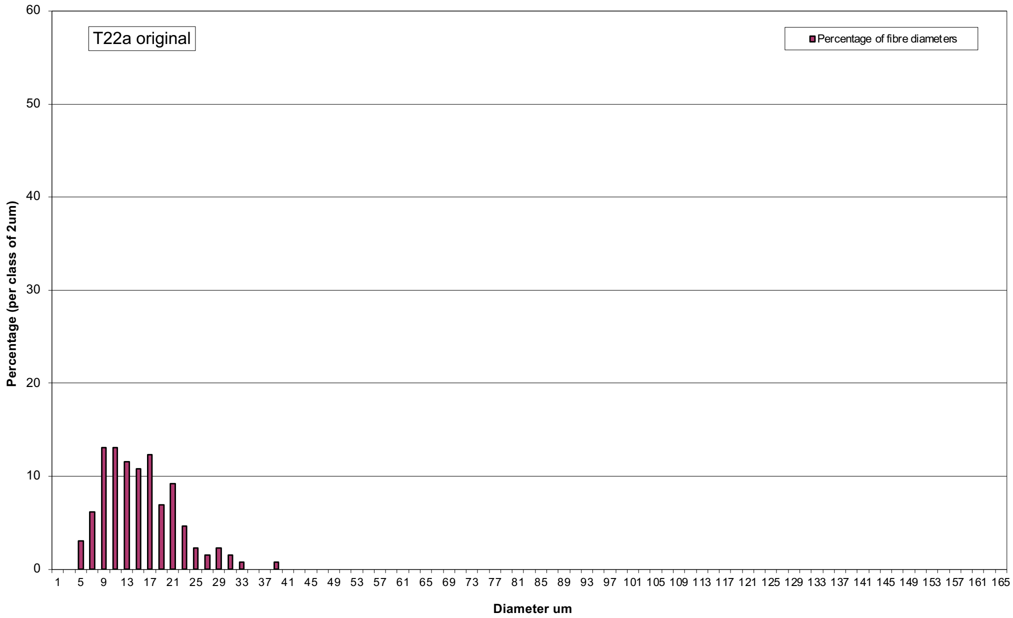
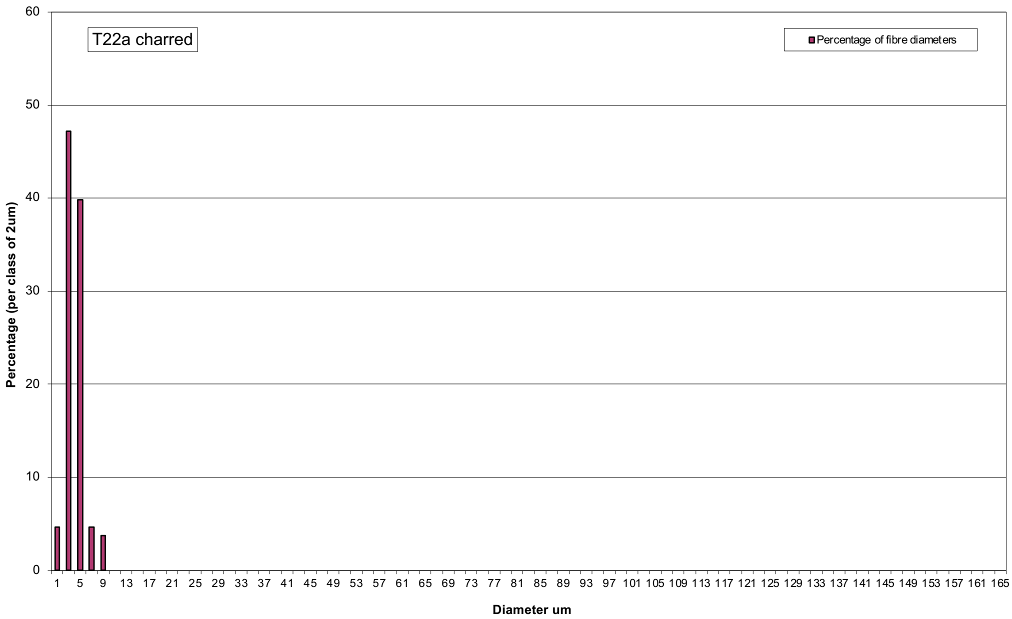


Figure 10a–b. Textile 19, histograms of fibre diameters: up – original; down – charred. (Images: M. Gleba)

26.6. Conclusions

The preliminary overview of the cremation and charring experiments presented here indicates that textiles can survive both open fire and indirect high temperatures. While wool does not appear to survive above 250–300 ˚C in controlled experiments, the situation appears to be different with archaeological samples and those from open-fire cremation experiments. This clearly requires further investigation. Linen textiles, on the other hand, can survive up to 1000 ˚C, and although they shrink substantially, the characteristic morphological features survive in the fibres. Furthermore, the degree of shrinking appears to be temperature-dependent, allowing us to use – with due caution – the experimental data to estimate the temperature at which archaeological samples may have been subjected to fire. These findings provide a greater understanding for the detailed conditions under





Figures 10c–d. Textile 22a, histograms of fibre diameters: up – original; down – charred. (Images: M. Gleba)

which textiles might survive charring in an archaeological environment. This knowledge can give us a better idea of where textiles may be found within an archaeological site, how they might appear during excavation (recognisable as fabric, ground into microscopic particles, etc.) and how they should be removed and analysed. The next step in experimental research will be to pursue further investigation into the impact of taphonomic conditions on charred textiles (how they react when buried in the soil), as these appear to play a major role in their preservation. For this, in November 2020 a further long-term experiment was initiated at the Museum Asparn, which re-interred charred textiles from the cremation experiments in urns (Fritzl et al. 2021). They will be re-excavated in 10 years.

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KG wrote up the Asparn Experiments; MG wrote Cambridge experiments and results of Asparn experiment analysis; SVH provided data for Cambridge experiments; KG and MG co-wrote introduction and conclusions.

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