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Investigating Wool Fibres from Danish Prehistoric Textiles

Introduction

Analysis of prehistoric textile fibres by means of a transmitted light microscope or a scanning electron microscope is a method used for identifying fibre materials, distinguishing characteristic features in the surface structure of fibres and determining the degree of degradation of a textile. The study of wool fibre fineness by measuring fibre diameter is an additional possibility for characterising fibres. The latter method was developed by the wool industry. It was adapted to the study of prehistoric fibres by Michael L. Ryder from the 1960 to the 1980s and further applied by, among other scholars, Penelope Walton and Jerzy Maik (Bender Jørgensen and Walton 1986; Maik 1998; Ryder 1969; 1983; Walton 1990). By comparing the measurements from prehistoric wool fibres, in particular to the so-called primitive sheep breeds, Ryder was able to draw conclusions about ancient sheep breeds and determine the fleece types of prehistoric sheep. Wool samples from several of the prehistoric Danish textiles were used to qualify the kind of fleece available at the time.

Recently, systematic investigations of wool fibres from prehistoric Danish textiles have been undertaken by the Danish National Research Foundation's Centre for Textile Research as part of a project studying Danish Bronze and early Iron Age textiles. This has resulted in a large amount of new information, for instance regarding the production, provenance and design of the textiles. In collaboration with the National Museum of Denmark, analysis of wool fibre diameters began with the early Iron Age bog textiles. It was planned not only to follow the standards developed by Ryder, who used statistical calculations of a minimum of 100 measurements from each yarn and plotted these into histograms to distinguish fleece types (Ryder 1969; 1983, 45-49), but also to implement the method

developed by Antoinette Rast-Eicher which uses a new categorisation system to interpret the processing of the raw wool (Rast-Eicher 2008, 153-155).

Rast-Eicher's system is based on a categorisation of sheep's wool developed in the late 19th and early 20th centuries (Stieger 1888; Frölich *et al.* 1929) with a distinction between four main wool types, and a classification of wool qualities such as underwool, medium fibres and hair or kemp based on the percentages of fibre types. By looking at parameters such as the number of fine fibres, the uninterrupted range, the mode and the maximum measurements, Rast-Eicher has introduced a classification system containing 11 different categories. The categories are labelled using different combinations of capital letters, AAA being the group with the highest percentage of fine fibres and F the group with the lowest (Rast-Eicher 2008, 155).

The first results from the Danish early Iron Age bog textiles were surprising, not so much because of the fleece type that the histograms illustrated but because of the fineness of the fibres measured and the extent of homogeneity. The measurements differed from previous reports (Bender Jørgensen and Walton 1986; Ryder 1990; Walton 1990) and initiated a study of the methodology, with crosschecking of the results using different methods and different magnifications of capturing images resulting in an increased interest in analyses of fibres from different archaeological contexts (Skals *et al.* forthcoming). Textiles from Roman Iron Age burials were added to the analyses and an extensive analysis of the textiles from the Bronze Age is in its final stages. Altogether this has yielded invaluable information about the wool available for garments from roughly 1500 BC to AD 400.

The methodology and the results from the investigation of the different ways of capturing

images are described in detail elsewhere and the focus in this article will be on the interpretation of the results (Skals *et al.* forthcoming). It should be noted that in some of the analyses the photos were captured at 40x magnification whereas it was at 100x magnification in others. The measurements can be made with greater precision and are generally higher by a few microns at higher magnification but this does not make any difference to the extent of homogeneity. Plotted in the histogram the curve of the peaks from the results at low magnification will be positioned slightly more to the right on the x-axis (Fig. 1).

An important parameter extracted from the fibre measurements is whether the statistical mode, i.e. the most commonly occurring diameter measurement, is below or above 20 microns. The reason why this is important is because wool from the wild ancestor of sheep had a fleece consisting of many very fine fibres with a mode below 20 microns and bristly kemp fibres which could measure more than 100 microns. The evolution of sheep and their fleece has shown that wool fibres gradually became more uniform and the coarse kemp disappeared, which resulted in a coarsening of

the mode. The mode is therefore an indication of how closely related the sheep that provided the wool for the textiles were to their wild ancestors (Ryder 1969; 1983, 45-49; 1990; Rast-Eicher 2008, 121-122).

Another important parameter is the range of the measurements. Each histogram will, expressed in percentage terms, have a coherent range consisting of the majority of the fibre measurements, but can also have outliers which will show up as small peaks along the x-axis. The peak heights are determined by the percentage measurements calculated in two micron intervals (Fig. 2). The quantity of the outliers and their position on the x-axis are a further indication of the wool type, but are also indicative for the interpretation of the way it was processed. As the mix of very coarse fibres measuring more than 100 microns and even fibres measuring more than 60 microns with the very fine fibres would have made spinning more difficult, the number of coarse fibres in the textile samples is interpreted as reflecting attempts to deliberately remove the coarse hair before spinning (Rast-Eicher 2008, 123).

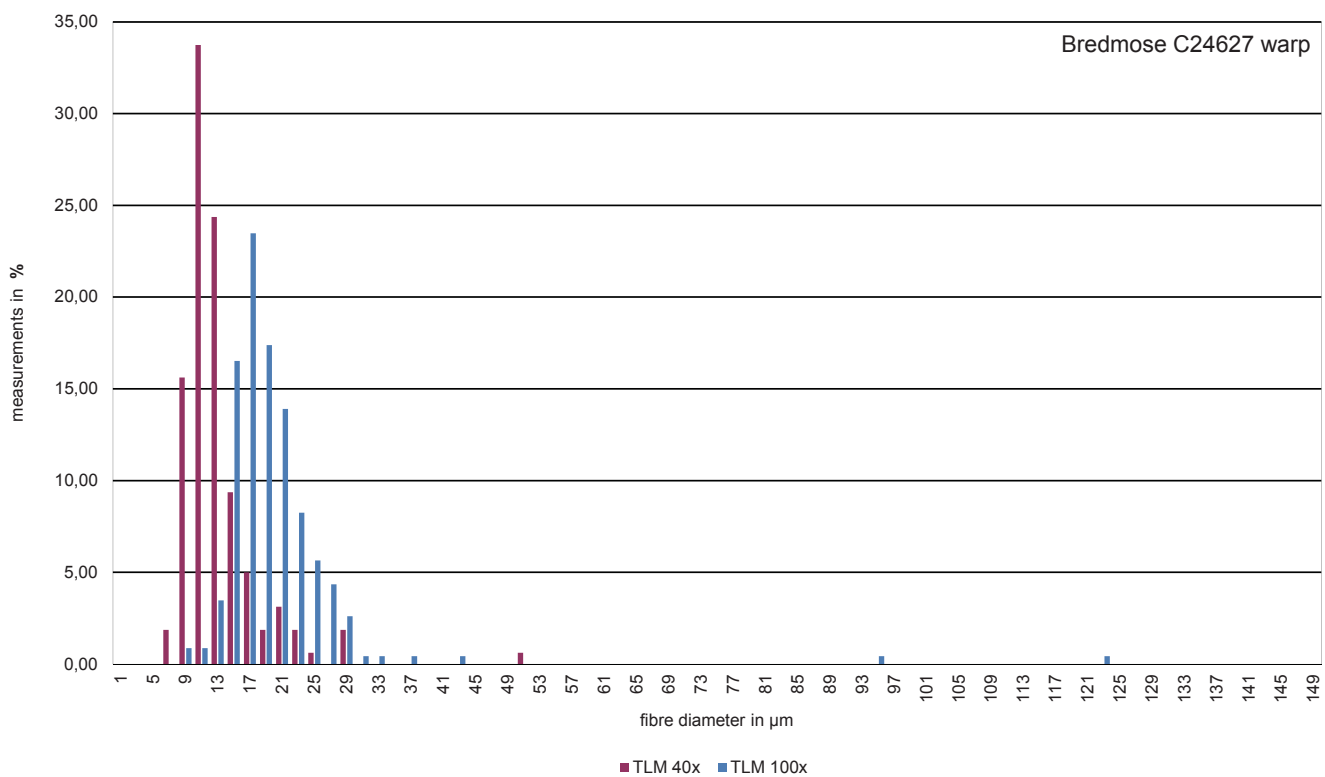


Fig. 1. Two separate pieces of the same yarn sample from a Danish early Iron Age bog textile was analysed at 40x and 100x magnification. The coherent curve from the measurements using low magnification is slightly to the left of the one from measurements using high magnification. The difference in the amount of outliers is due to the fact that different parts of the yarn sample were analysed.

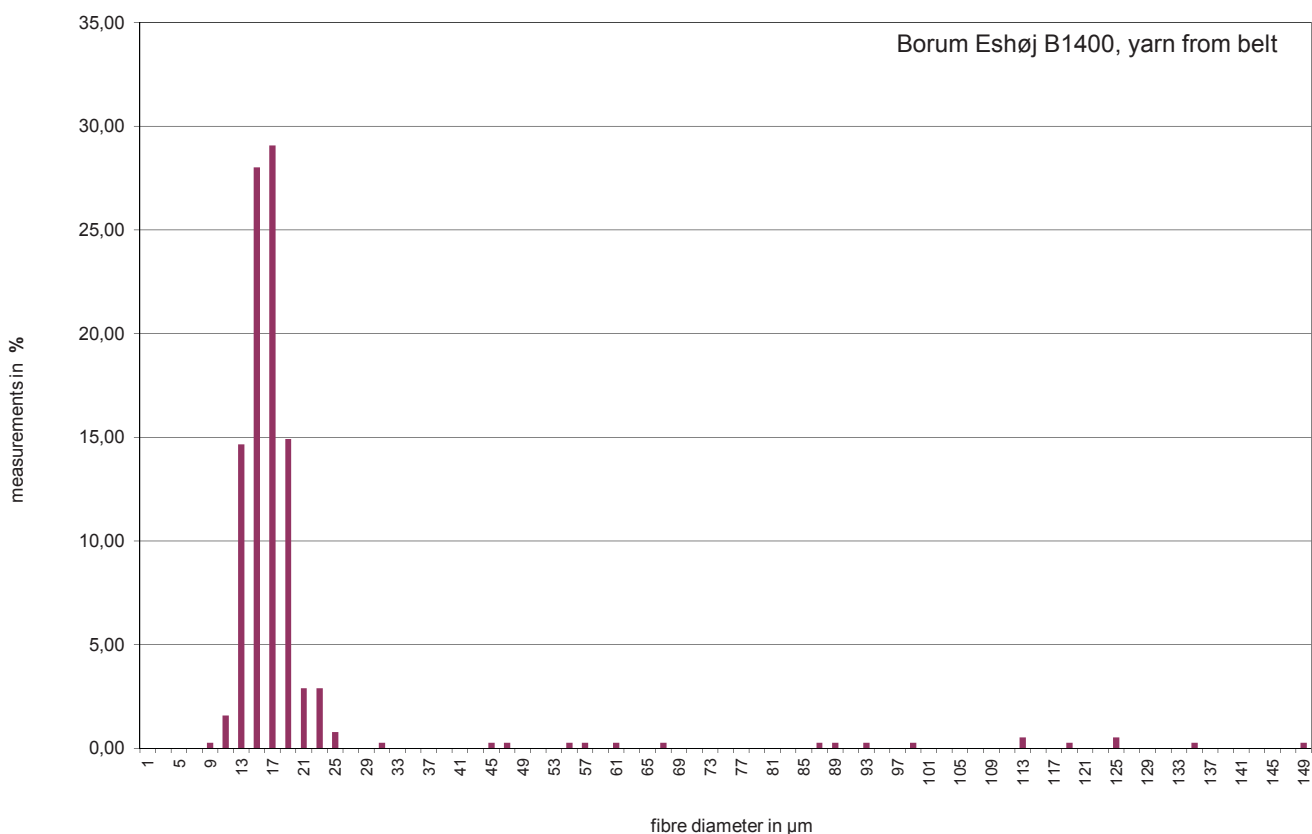


Fig. 2. This histogram shows the distribution of wool fibres in a Danish early Bronze Age textile. The fibre distribution with many fine fibres is indicated by a narrow coherent range while the many coarser outliers are spread along the x-axis.

The fibre analyses of several contemporary sheep fur garments preserved in the Danish bogs have shown that these furs do not represent a standard textile fleece with a mix of fine and coarse fibres but appear to have been chosen for their special fibre qualities and with a specific use in mind (Mannering and Gleba forthcoming). Although the fibre diameter measurements from the textiles show a clear connection between the wool in the textiles and the furs, the furs do not represent the unprocessed prehistoric wool, but were selected specifically for their fine and soft appearance (Ørsted Brandt *et al.* 2014). On this basis it must be concluded that the amount of coarse fibre in the original raw wool used for the Danish prehistoric textiles is still not known. An evaluation of the way the fibres were processed is thus best assessed by comparing the ranges of the diameter measurements and the amount of outliers in the yarn samples.

Fibres in Danish early Iron Age bog textiles

Many of the Danish early Iron Age bog textiles have patterns of checks and stripes in different colours and

26 of these textiles were selected for fibre analysis with the aim of covering a period from c. 800 BC to AD 400, representing different types of garments, weaves and qualities. This has resulted in analyses of samples from 68 yarns. Two samples from each type of yarn in the textiles were picked at random. The fibres were measured on digital images captured using transmitted light microscopy and the results from the two yarn samples were combined to secure maximum statistical significance.

The calculations of the mode turned out to be below 20 microns in all samples with a large majority at 13 microns (Fig. 3). This is not only an indication of a significant homogeneity in the wool but also explains the extreme softness of these textiles, as this depends on the fineness of the fibres. It should be borne in mind that the exact position on the x-axis of the mode can vary up to a few microns depending on the method of fibre measurement and the magnification used for capturing the fibre images, but nevertheless it is evident that the Danish early Iron Age wool was very fine (see Fig. 1) (Skals *et al.* forthcoming).

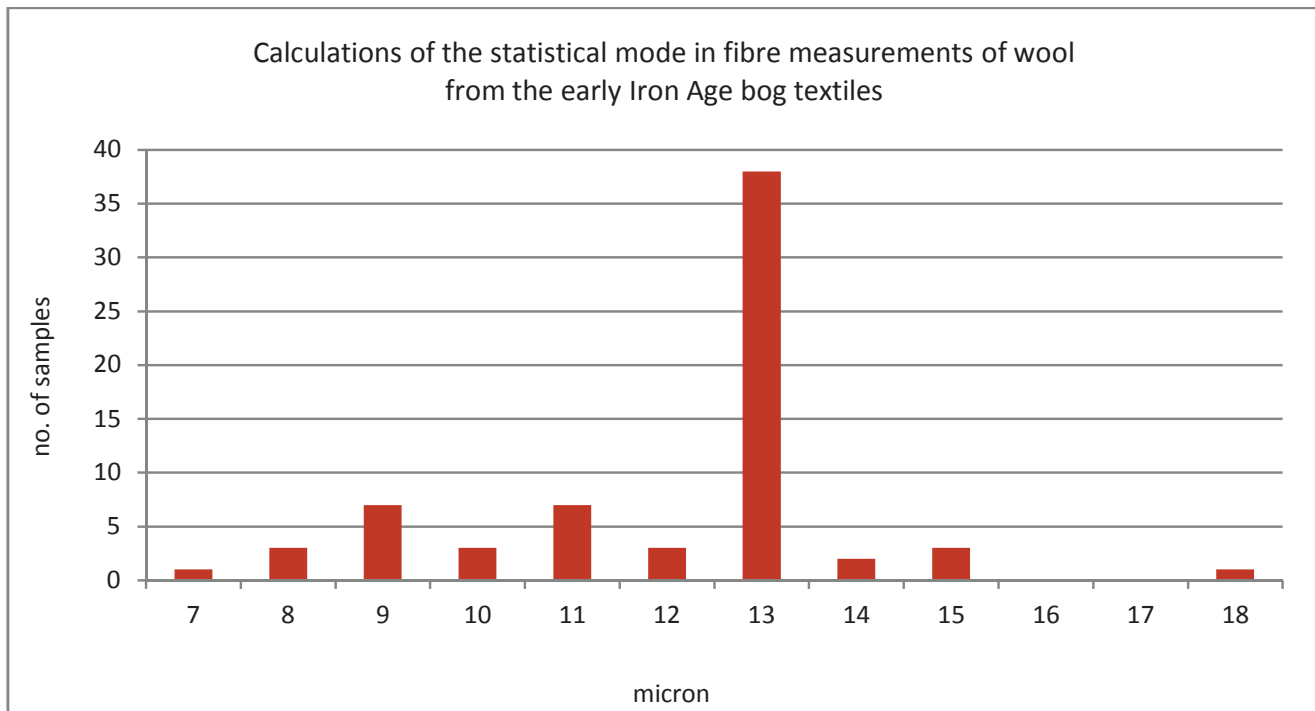


Fig. 3. The wool from the Danish early Iron Age bog textiles appears very fine and homogeneous and the statistical mode is in most cases 13 microns. These results were obtained using 40x magnification and referring to Fig. 1 they can be slightly higher using a higher magnification but would still be below 20 microns.

We found similar homogeneity in the range of fibre measurements and the amount of outliers. In 32 of the 68 samples the fibres measured less than 30 microns and in a further 15 samples only one outlier was detected (Table 1). This makes it possible to characterise the wool processing method solely by the number of outliers above 30 microns. In the categorisation system the coarseness of the outliers as well as their amount determine the assignment of the category and the characterisation of the wool will appear slightly different (Fig. 4). In the present investigation, 35 samples are categorised as AAA according to Rast-Eicher's system representing samples with only 1% of the measurements above 30 microns and none above 40 microns. The categories AA, A and AB are samples with increasing amounts of outliers between 40 and 60 microns and represent a very small number of samples.

The second largest group of 18 samples are assigned to category B. The fibre combinations in these samples are 99-94% of the fibres measuring less than 25 microns and 1-6% measuring more than 60 microns.

It is not because of a decrease in the number of fine fibres but because of the coarseness of the outliers that the samples are categorised as B. In this case, the borderline of 60 microns for the coarse fibres is more important than the high number of fine fibres. This distinction is made because fibres measuring more than 60 microns are generally defined as 'hair' and above 100 microns as 'kemp', but in the case of these wool samples it seems that category B fails to give the proper impression of the fineness of the wool. The same applies to the remaining ten Danish early Iron Age textile samples, which are categorised as CD, D and E. All of these have very high percentages of fine fibres (above 90%) and 1-6% of outliers measuring more than 60 microns.

An additional factor that has complicated the use of the known categorisation systems is the fact that during our investigations it became apparent that the coarse fibres were very unevenly distributed in the yarns. We found that two separate analyses of fibres cut from the same yarn sample could give quite different results (Skals *et al.* forthcoming). This illustrates the



Categorization of wool from early Iron Age bog textiles

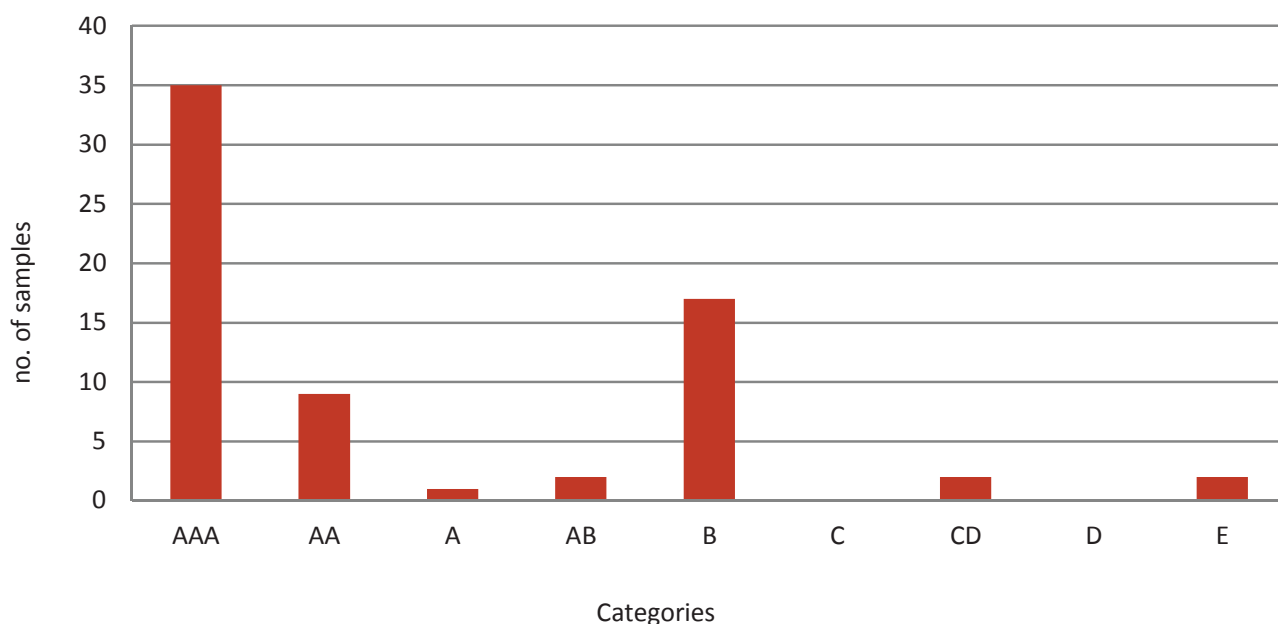


Fig. 4. The homogeneity of the diameter measurements from the early Iron Age burial textiles is illustrated by the very high number of samples in category AAA. Category B represents samples with a very narrow uninterrupted range and 1-2% fibres coarser than 60 microns.

Table 1. Many samples have no coarse fibres and in 15 samples only 1% of the diameter measurements are above 30 microns. Between three and ten % coarse outliers are recorded in a few samples.

Range and % of outliers in fibre diameter measurements. Wool from Early Iron Age bog textiles.										
range	% of outliers in samples									
measurements	0	1	2	3	4	6	8	9	10	no. of samples
only $\leq 30 \mu$	32	0	0	0	0	0	0	0	0	32
$\leq 30 \mu + \geq 30,5 \mu$ and $\leq 60 \mu$	0	7	4	1	1	1	0	0	1	15
$\leq 30 \mu + \geq 60,5 \mu$	0	8	3	0	0	0	0	0	0	11
$\leq 30 \mu + \geq 30,5 \mu$ and $\geq 60,5 \mu$	0	0	3	2	2	0	2	1	0	10
no. of samples	32	15	10	3	3	1	2	1	1	68

Calculations of the statistical mode in fibre measurements of wool from Iron Age burial textiles

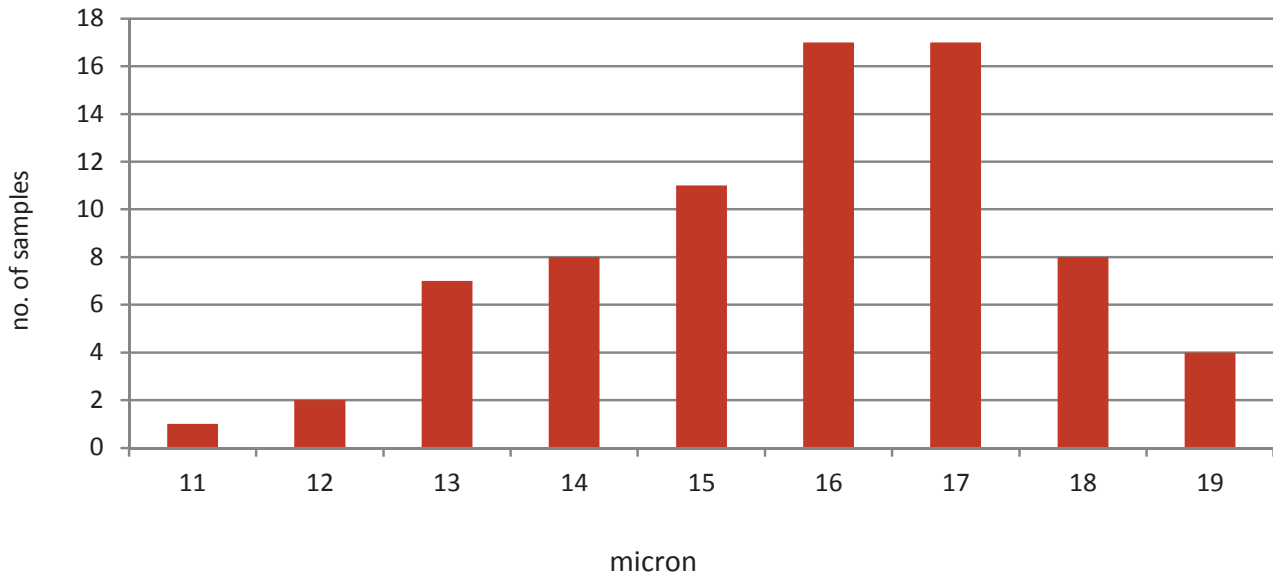


Fig. 5. This diagram sums up the statistical mode calculated from the diameter measurements from the early Iron Age burial textiles which appears different from the bog textiles (cf. Fig. 3). The measurements were made using 100x magnification and the mode is nonetheless in all cases less than 20 microns.

complexity of the textile materials and accentuates the need for evaluation and constant testing of our methods and interpretations, and we recommend that scholars take as many samples and measurements from each yarn as possible to give the statistically most reliable results.

Fibres in Danish early Iron Age burial textiles

Textile samples from 12 early Iron Age graves dated c. 100 BC-AD 300 from three different locations were also selected. All together analyses of 75 different yarns from 35 textiles were made. Compared to the bog textiles, these textiles are considerably more degraded and in most cases constitute only small and extremely fragile pieces. Nevertheless, the results are very similar to the bog textiles and the calculations of the mode are also in these cases below 20 microns and in most cases at 16 and 17 microns (Fig. 5). The reason for the mode being three to four microns higher is believed to be due to the use of higher magnification for capturing the images (see Fig. 1) (Skals *et al.* forthcoming).

The amount and distribution of the outliers in these textiles are similar to the bog textiles. Almost half

of the yarns have no outliers and an almost equal number have only one or two outliers. In 13 samples, five to ten outliers were found (Table 2). Category AAA was given to 37 samples and a much smaller number are placed in the following two categories, whereas category B has the second highest number of samples due to 1-2% of outliers measuring more than 60 microns (Fig. 6).

Fibres in Danish Bronze Age burial textiles

So far, 73 yarn samples from 31 textiles have been analysed from the large Danish collection of textiles dated to the early Bronze Age (c. 14th-12th centuries BC). A narrow majority of the samples have a mode at 13 microns and in most cases it is below 20 microns, but compared to the early Iron Age bog textiles a greater variety is seen in the calculations which possibly indicates slight differences in the fibre combination of the raw material (Fig. 7).

The results of the diameter measurements also differ from the early Iron Age textiles by the amount of outliers, which is considerably higher. In only four cases all fibres measure less than 30 microns. In more



Table 2. The amount of coarse outliers is limited in the wool samples from the early Iron Age burial textiles. From three to ten % coarse outliers are recorded in one to five samples.

Range and % of outliers in fibre diameter measurements. Wool from Iron Age burial textiles.										
range	% of outliers in samples									
measurements	0	1	2	3	4	5	6	8	10	no. of samples
only $\leq 30 \mu$	32	0	0	0	0	0	0	0	0	32
$\leq 30 \mu + \geq 30,5 \text{ and } \leq 60 \mu$	0	10	6	5	2	1	0	0	1	25
$\leq 30 \mu + \geq 60,5 \mu$	0	10	0	0	0	0	0	0	0	10
$\leq 30 \mu + \geq 30,5 \text{ and } \geq 60,5 \mu$	0	0	4	0	2	0	1	1	0	8
no. of samples	32	20	10	5	4	1	1	1	1	75

Categorization of wool from early Iron Age burial textiles

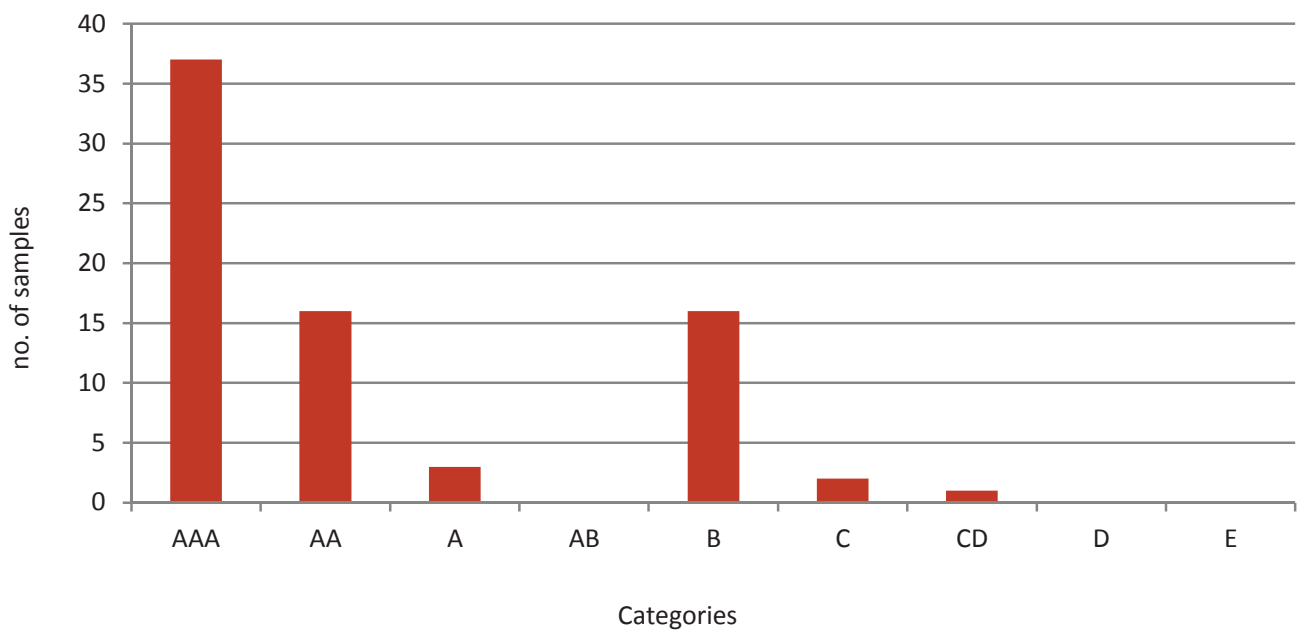


Fig. 6. The diagram of the categorisation of the wool from the early Iron Age burial textiles resembles the one for the contemporary bog textiles with high peaks for categories AAA and B.

Table 3. In the early Bronze Age, coarse fibres are common and samples without any coarse outliers are rare.

Range and % of outliers in fibre diameter measurements. Wool from Bronze Age textiles.											
Range	% of outliers in samples										
measurements	0	1	2	3	4	5	6	7	10	12	no. of samples
only $\leq 30 \mu$	5	0	0	0	0	0	0	0	0	0	5
$\leq 30 \mu + \geq 30,5$ and $\leq 60 \mu$	0	3	6	0	1	0	2	0	0	0	12
$\leq 30 \mu + \geq 60,5 \mu$	0	4	3	6	1	1	0	0	0	0	15
$\leq 30 \mu + \geq 30,5$ and $\geq 60,5 \mu$	0	0	4	14	6	11	3	1	1	1	41
no. of samples	5	7	13	20	8	12	5	1	1	1	73

Calculations of the statistical mode in fibre measurements of wool from Bronze Age burial textiles

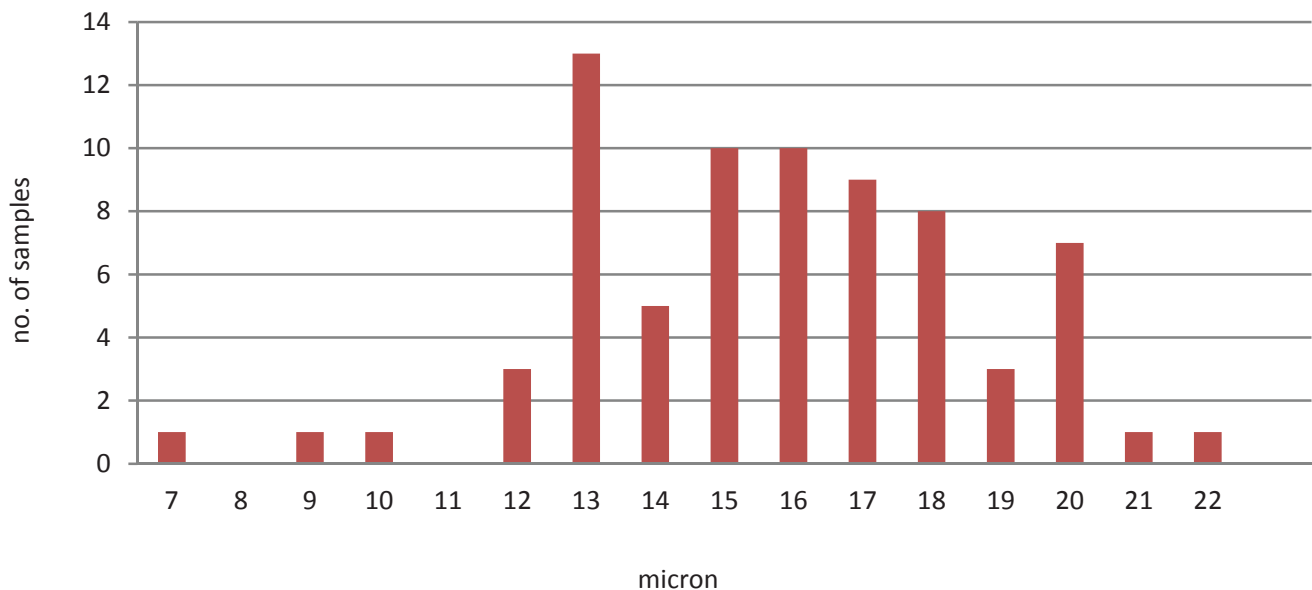


Fig. 7. Many wool samples from early Bronze Age textiles have modes that are below 20 microns, but in two samples it is just above 20 microns.

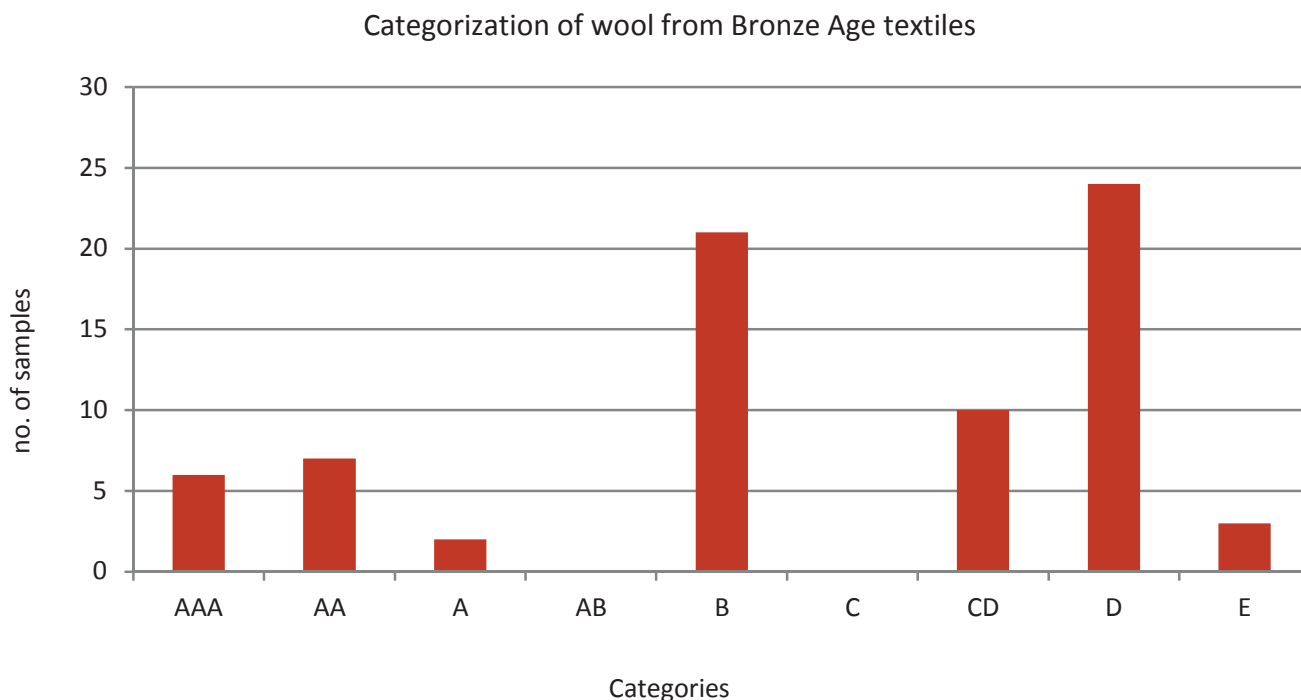


Fig. 8. The large amount of coarse fibres in the early Bronze Age wool is illustrated by the high peaks belonging to categories B and D.

than half of the samples, up to 14 outliers were recorded of which several measure more than 60 microns (Table 3). This is also reflected in the categorisation where the majority of the samples are placed in categories B and D (Fig. 8). Category B is given to samples with one to five outliers measuring more than 60 microns. Unfortunately, no sheep skins have been identified in a Danish Bronze Age context that can be compared to the textiles.

Evaluation and interpretation

During this process of measuring wool fibres from the prehistoric textiles and furs, including the necessary investigation of the methodology, it has turned out that analysis of wool fibre diameter measurements is more complex than anticipated. We discovered that different methodologies like scanning electron microscopy and transmitted light microscopy, and the use of different magnification for capturing the fibre images especially in the light microscope, can give different results. We discovered that the exact same results could not be reproduced from a different sample from the same yarn because of an uneven distribution of the fine and coarse fibres in the yarns. We found that these differences result in slight variations in the calculations of the mode and can result in a

different categorisation of two samples from the same yarn. Moreover, we found that the categorisation of samples with narrow uninterrupted ranges below 25 microns and only one percent of outliers above 60 microns needs to be further discussed and evaluated. These discrepancies are extensive and the results from fibre quality analyses need to be carefully discussed and developed before further interpretations can be attempted.

Nevertheless, our results show that wool for textiles in the Bronze and early Iron Ages consisted to a large degree of very fine fibres measuring less than 20 microns, which is extraordinarily fine. Fibre measurements from textiles and furs from Bronze Age finds from Norway, Sweden, Bosnia and Hercegovina have resulted in ranges similar to ours from the lowest measurements of 5-10 microns to between 20 and 30 microns, whereas the results from the Hallstatt wool and furs in most cases show ranges from 9-19 microns to 27-57 microns, although two results have ranges from 7-27/29 microns respectively which could possibly be compared to our results (Rast-Eicher and Bender Jørgensen 2013).

We think that the key parameter for the interpretation of the wool preparation lies in the difference in the amount of coarse fibres before and after spinning,



and as no unprepared material exists we must use the amount of coarse fibres in the preserved fleeces and the differences in the amount in the yarns to evaluate this. Our results show that a change in the fibre content of the yarns takes place from the Bronze Age to the Early Iron Age. This is observed in the decrease in the amount of outliers and as the fibre distribution pattern of fine fibres in both periods are similar it indicates that Bronze Age wool was spun without a thorough removal of coarse fibres while in the early Iron Age coarse fibres to a large extent were removed deliberately.

This does not mean that Bronze Age wool in Denmark was not sorted at all before spinning. Dye analyses of the yarns from the Bronze Age textiles have all been negative, but it is still possible to distinguish conscious use of colours in the wool yarns caused by differences in the natural pigmentation in the fibres. This implies that some sorting according to colour took place, while it was not considered important to remove all the coarse fibres. Patterning using pigmented fibres is seen in the early Iron Age bog textiles. Here it co-exists with plant dyeing technology and a more widespread use of white wool (Vanden Berghe *et al.* 2009).

Other analyses of the wool fibres such as strontium isotope analysis have added a further interpretational dimension to fibre studies. Using a systematic analysis of the wool from one of the early Iron Age garments – the so called Huldremose II costume – it was discovered that the wool came from three different locations, of which two were outside the present Danish area. This fact was not visually distinguishable in the yarn for this garment. Neither the measurements of the twist angle nor of the results from the fibre measurements indicated any difference in the wool fibre composition (Frei *et al.* 2009). The non-local wool used in this garment must therefore have been traded but processed locally. As this was the first textile to be tested in this way, we now have to be open to the possibility that wool was traded over long distances and that textiles which to the naked eye look homogeneous may contain wool from mixed fleeces and possibly even different sheep breeds. This is definitely a surprising discovery that emphasises the need for diverse and cautious interpretations.

Although the interpretation and understanding of the results from fibre analyses have proven to be more complicated than expected and new questions have turned up, new information has also been obtained. It can be concluded that the sheep wool used in the Danish Bronze Age textiles mainly consisted of very fine fibres mixed with a varied amount of coarser fibres and kemp and sorted according to colour. No difference can be observed in the wool used in the early

Iron Age textiles from bogs and burials but this differs from Bronze Age wool in having a more uniform fibre combination with only occasional coarse fibres and kemp. The results from c. 1500 years of textile production do not indicate any outstanding differences in the raw material and the absence of coarse fibres in the early Iron Age bog and burial textiles is believed to be a result of processing, determined by factors such as the time of year for harvesting or a meticulous sorting of the wool. The discovery of the mixture of local and non-local wool in one textile adds a different dimension to the question of fleece type. It appears that the raw wool did not necessarily come from only one flock of sheep and may have been transported over long distances before it was mixed with local wool and made into yarn in this part of the world.

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