Dislocations in plant fibres and in Turin Shroud fibres

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Abstract
Some natural fibres contain dislocations, i.e. regions where the cell wall structure differs from that of the surrounding cell wall. Dislocations have also been found in Turin Shroud fibres. This paper gives an introduction to dislocations in plant fibres and dislocations found in flax fibres from the Turin Shroud are compared to dislocations in plant fibres of modern origin. None of the characteristics measured differed sytematically between Turin Shroud flax fibres and hemp fibres extracted from plants at harvest. However, fibres extracted from modern hemp yarn contained larger dislocations than the Turin Shroud fibres.

Keywords: Dislocations, slip planes, flax, hemp.

1. INTRODUCTION

The Turin Shroud is made mainly from flax textile fibres, and in this paper the dislocations within the cell walls of these fibres are studied. Dislocations are irregular regions within the cell wall and are present in several different plant fibres and tracheides already in the living plant. This is for example the case in flax, hemp and wood. A few natural fibres do not contain dislocations at the time of harvest. Cotton is an important example. Incidentally, neither silk nor wool contain any dislocations either. These materials originate from animals and consist of protein. Dislocations have also been called slip planes or nodes, but here the term 'dislocation' is used in accordance with [1]. Dislocations are not locations of cell wall formation / cell elongation, i.e. they contain no meristems and are thus not at all related to the macro-scale growth nodes (the so-called 'knees') present in grasses, in spite of the superficial likeness in appearances. Figure 1 shows two flax fibres from the Turin Shroud. The white bands across the fibres are the dislocations, which are here made visible by use of cross polarized light. Dislocations are normally not discernable using bright field light microscopy or using scanning electron microscopy [2], as they often affect only the inner secondary cell wall and not the outer primary wall.

The exact structure and composition of dislocations remains unknown. They are assumed to contain mainly cellulose, lignin and hemicellulose like the rest of the secondary cell wall. Traditionally dislocations are considered to contain amorphous cellulose in contrast to the surrounding cell wall, which contains crystalline cellulose. However, recent results indicate that this assumption is not correct as dislocations are birefringent just like the bulk cell wall [3], which indicates that the structure is not amorphous. By applying tensile load in the longitudinal direction of individual fibres, dislocations may be stretched and thus aligned with the cellulose microfibrils of the surrounding bulk cell wall [4], at least under some circumstances. This result indicates that the cellulose micro fibrils continue through the dislocations, i.e. dislocations may have a less 'ordered' and/or a more 'loose' structure, but they are not places where micro fibrils are discontinuous.

Figure 1. Polarized ligth microscopy image of two flax fibres from the Turn Shroud showing dislocations as white bands across the fibres.

As mentioned above, dislocations are present already in the living plant. They may however also be introduced during processing [5, 6]; compression strength applied in the longitudinal direction of the fibre will under some circumstances introduce dislocations. One may perhaps envision the process as an originally stretched accordion being pushed together. However, on the molecular level, intra-fibril and intra-fiber bonds are much stronger than inter-fibril and inter-fiber bonds. This means that both fibres and fibrils are less prone to forming dislocations than to shear (i.e. to glide past each other and breaking and reforming Hydrogen bonds, in a Velcro-like process). Which process is favoured is probably affected also by the moisture content as water is known to markedly reduce the glass temperature of lignin and hemicellulose. In other words, a dry fibre is less flexible.

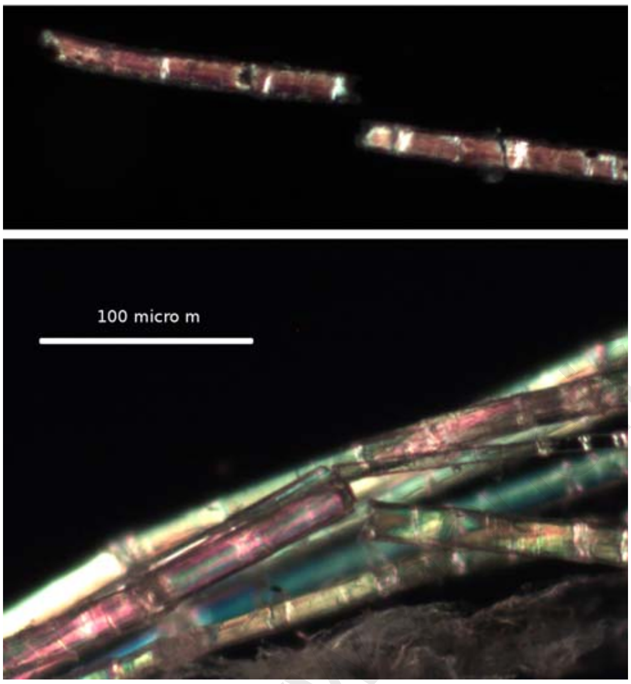

Figure 2. Two polarized ligth microscopy images of flax fibres from the Turin Shroud (top) and from a 1000 BC Lyme mummy wrapping (bottom). Both images show fibres broken in dislocations. The scale bar applies to both images.

Some of the characteristics of dislocations have been reported in the literature. Regarding long textile fibres such as flax and hemp, dislocations are known to bind dies better than the surrounding cell wall [7]. Other studies have shown that dislocations are more susceptible to hydrolysis than the bulk cell wall [3,8,9]. These results indicate that dislocations are more susceptible/reactive than the surrounding cell wall, i.e. they are in a sense the 'weak spots' of the fibres. Figure 2 shows Polarized Light Microscopy (PLM) images of Turin Shroud flax fibres and of flax fibres from a 1st century BC Lyma mummy wrapping. In both cases the fibres are seen to break into segments at the dislocations.

In the present study PLM and image analysis was used to measure the amount of dislocations, their sizes and the distance between them in five different data sets consisting of plant fibres: Turin Shroud flax fibres, hemp fibres extracted at harvest from plants grown under three different growth regimes ('wind free','windy','dry') and hemp fibres extracted from modern hemp yarn. The values are compared in order to determine whether the Turin Shroud fibres investigated differ from modern textile fibres with regard to dislocations. It is a weakness of the study that the Turin Shroud flax fibres are compared to modern hemp fibres and not to modern flax fibres. However, these two fibre types have similar dimensions and properties, which in the author's opinion justify the comparison. In a recent publication, it was pointed out that the two species may not be separated from each other using light microscopy [10].

2. EXPERIMENTAL

The modern fibres included in this study comprised four different hemp (*Cannabis sativa*, L.) fibre sets, each consisting of around 100 fibres. Three of these fibre sets were extracted from hemp stems by hand using precision tweezers. The hemp plants had been grown in a green house under three different growth conditions: 'wind free', 'wind' and 'drought'. The 'wind free' regime implied no wind at all during the growth season of the plants, and no lack of water or nutrients. The 'wind' regime implied wind night and day throughout the growth season; the wind came from constantly changing directions. The 'drought' regime implied wind free conditions, but minimum amounts of water and nutrients. For further details, please refer to [11]. The fourth set comprised fibre segments extracted from commercial hemp yarn, please refer to [9] for further details. The data used here is the reference data set of that study.

The Turin Shroud flax fibres included in the study were selected from two sets of fibre samples provided 2009 and 2010 by Professor Giulio Fanti, University of Padua. The fibres from a mummy wrapping (shown in Figure 2) were also supplied by Professor Fanti.

For the modern fibres, the dislocations in each of the fibre segments were identified by image analysis of micrographs obtained from polarized light microscopy using the automated method described in [12]. Based on the fibre and dislocation image masks produced by this method, three different parameters were calculated, all based on the 2D transmission images obtained from PLM: a) the relative dislocation area, i.e. the area of the dislocations in percentage of the fibre segment area, b) the absolute areas of the individual dislocations and c) the absolute longitudinal distances between neighbouring dislocations. The relative dislocation area was calculated for each individual fibre segment image, while all values found for each of the other two parameters were pooled for all fibre segment images within each data set.

For the Turin Shroud fibres, fibre and dislocation masks were drawn by hand and the same three parameters as for the modern fibres were calculated based on these masks. The reason why the automated method of [12] was not used for these fibres was that the method gives good estimates of mean values for populations of fibres, while values for individual fibres are less trustworthy [12]. Since only 20 fibre segments were analysed for the Turin Shroud flax fibres, the more cumbersome, but more trustworthy method of manual masking was chosen.

Table 1 gives an overview of the results. Regarding the relative dislocation area, the table shows that for hemp fibres at harvest, up to about 20 % of the cell wall consist of dislocations at harvest (the column marked ‘Mean’ for the ‘Relative dislocation areas’). When comparing to the 12 % found in the wind free case, it can be seen that both wind and drought introduce dislocations, as reported earlier [11]. The growth conditions in this green house test were unusually harsh compared to European weather conditions, so natural textile fibres most likely contain somewhat less dislocations, but more than what was here found in the completely wind-free case, which may be seen as a lower boundary regarding the amount of dislocations in hemp fibres at harvest. The results confirm that industrial processing into yarn introduces more dislocations into the fibres. The Turin Shroud flax fibres are seen to contain the same amount of dislocations as modern hemp yarn fibres, the small difference seen in the relative dislocation area is not significant. However, when comparing the mean size of the dislocations found in these two samples, the dislocations in the Shroud fibres are seen to be significantly smaller than those found in the modern hemp yarn fibres, on average only about half the size. The size of the dislocations in the Shroud fibres is not significantly different from those found in the ‘wind’ and the ‘drought’ data sets. Perhaps the difference in dislocation sizes between the two processed fibres types is due to the modern hemp yarn being processed industrially while the textile fibres used for the Turin Shroud were manufactured by a gentler process resulting in more moderate damage. Regarding the average longitudinal distance between dislocations, the Turin Shroud fibres are not significantly different from the two harsh growth conditions, again suggesting a relatively mild processing. Surprisingly, the mean distance between neighbouring dislocations is seen to increase in the modern yarn compared to the average lengths found at harvest. A possible explanation to this is that the smaller dislocations disappear during processing due to stretching of the fibres. One can also imagine that dislocations merge with near by neighbouring dislocations, thus creating larger dislocations and removing the shortest distances. Dislocations in flax are known to sometimes cluster in certain regions rather than have an equal spread along the fibre [13].

Figures 3 and 4 give a more detailed representation of the results in Table 1. Figure 3 shows the cumulative frequencies of the dislocation sizes. The curve for the Turin Shroud fibres is seen to be close to the curves for the unprocessed fibres, but less smooth, again due to the smaller sample size. For these four sample sets almost all dislocations are seen to be smaller than approximately 200 μm^2. The dislocations in the yarn fibres are also mostly below this size, but about 15 % of them are larger than 200 μm^2.

Figure 4 shows the cumulative frequencies of the longitudinal distances between dislocations. For the two harsh growth conditions almost all distances are shorter than about 30 µm. The curve for the Turin Shroud fibres follows these two samples except for the last part as the maximum distances found are lower than for the two harsh growth conditions. However, the curve for the Turin Shroud fibres is based on a smaller data set and is consequently less smooth, so this result could be a coincidence. The wind free conditions resulted in longer distances between dislocations. For the three unprocessed fibre types as well as for the Turin Shroud fibres about 50% of the distances found are seen to be below 5 µm, while only about 20% of the distances are below this number for the modern hemp yarn.

TABLE 1. Data on dislocations in four different hemp fibre data sets. Mean values in the same column marked with the same letter are not significantly different (5% level or better according to t-tests). Columns marked ‘n’ give the number of observations, columns marked ‘Std’ give the standard deviations. Results marked $^{+)}$ are from [11].

Fibre source	Relative dislocation areas			Areas of dislocations			Longitudinal distances between dislocations		
	n	Mean [%]	Std [%]	n	Mean [μm^2]	Std [μm^2]	n	Mean [µm]	Std [µm]
Wind free (hemp)	96	$12.0^{a+)}$	8.5	1903	29^{a}	56	771	10.4^{a}	12.1
Wind (hemp)	98	$18.5^{b+)}$	12.8	2635	35^{b}	112	923	8.1^{b}	10.6
Drought (hemp)	114	$21.3^{bc+)}$	12.3	2783	41^{c}	116	959	8.0^{b}	9.4
Yarn (hemp)	95	24.0^{c}	9.6	1253	80^{d}	132	798	15.1^{c}	12.7
Turin Shroud (flax)	20	21.8^{bc}	10.1	267	38^{bc}	60	213	7.2^{b}	6.4

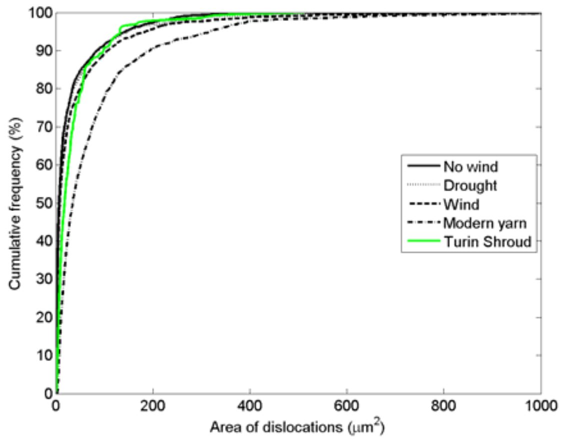

Figure 4. Cumulative frequencies for the absolute dislocation areas.

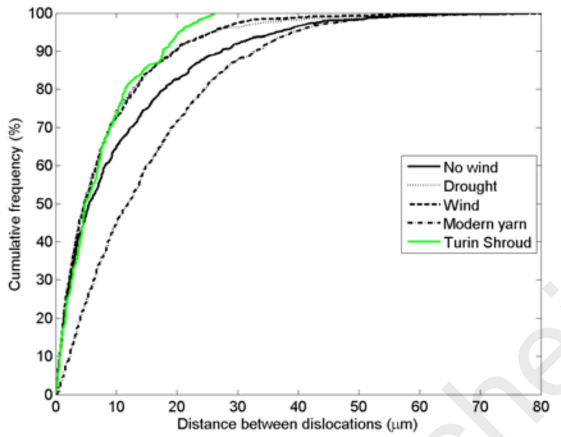

Figure 5. Cumulative frequencies for the longitudinal distances between neighboring dislocations.

3. CONCLUSIONS

Analysis of the dislocations in 20 flax fibre segments from the Turin Shroud indicated that the dislocations in Turin Shroud flax fibres appear to be similar in amount, sizes and distances to dislocations in modern hemp fibres. Regarding dislocations there is thus no indication that these fibres are different from other bast fibres. Dislocations are the weak spots of fibres, and some of the Turin shroud fibres investigated were seen to be broken into segments at the dislocations. This draws attention to the importance of handling these samples with care.

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