Physical Properties of Grass Fibres

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This article presents a detailed study of elementary grass fibres isolated from different grass sorts, i.e. Ryegrass, Wheatgrass, Trefoil and Lucerne. The fibre-samples were obtained in a bio-refinery, after the liquid phase containing proteins and lactic acid was eliminated from the siled and green grasses, respectively. Different processes for grass fibre separation from the rest of the plant were studied (e.g. acidic, alkaline and enzymatic treatment). They showed that, in comparison to the acid hydrolytic decomposition of the pectin structures, alkaline treatment causes some surface damage to isolated fibres but the enzyme treated fibres are of good quality. Additionally, the morphology of the elementary stem and leaf fibres were compared. Characterisation of the fibres regarding physical properties was performed, i.e., geometrical and mechanical properties.

Key words:
Grass fibres, morphology, physical properties

Introduction

The manufacture, use and removal of traditional materials are now considered more critically because of increasing environmental consciousness and the demands of legislative authorities. Natural cellulose fibres have successfully proven their qualities when also taking into account an ecological view of fibre materials.[1–2] Different cellulose fibres can be used for textile and technical applications, e.g. the bast or stem fibres, which form fibrous bundles in the inner bark (phloem or bast) of the stems of dicotyledenous plants, the leaf fibres which run lengthwise through the leaves of monocotyledenous plants, and the fibres of seeds and fruits.[3] Flax, hemp, jute, ramie, sisal and coir are mainly used for technical purposes.[1,4] Natural cellulose fibres are in the form of technical fibres, i.e. bundles of individual fibre cells held together by natural binding materials. Viewed as a cross-section, the fibre cell is polygonal, usually with either five to six sides or cylindrical in shape. It has thick walls and a broad lumen. On the fibre surface some deformation can be observed due to the mechanical process of fibre preparation. Natural cellulose fibres are relatively coarse and durable and posses a great biodegradable advantage.[5–7] Their excellent specific properties are high strength and stiffness. Beside conventional textile applications, natural cellulose fibres can serve as a light weight cores for composite materials and suitable insulation plates made of these materials provide excellent sound and thermal insulation.[1–2,8]

Alternative sources of cellulose raw materials have been studied recently. Grasses (Poaceae) form one of the largest plant families consisting of some 650 to 785 genera and about 10 000 species.[9–13] Members of this family occur abundantly in every climatic region and certain possibilities for their non-traditional application are evident, e.g. production of pulp and paper.[14–18] Perennial Ryegrass (Lolium perenne), Italian Ryegrass (Lolium multiflorum), Hybrid Ryegrasses (Lolium perenne x multiflorum), Timothy (Phleum pratense), Fescues (Meadow fescue – Festuca pratensis; Tall Fescue – F.arundinasea), are some of the most important representatives in this group of Grasses, while Legumes are presented by White Clover (Trifolium repens), Red Clover (Trifolium pratense) and Lucerne (Medicago sativa).[10,19–20] In cool – season grasses, which are adapted to cool climates, photosynthesis follows the C3 pathway.[21] The Panicoideae include many highly productive grasses and cereals, which follow C4 type photosynthesis.[21] Cereals, and especially wheat (Triticum), an annual plant, are the most important in this group.

Different tissues are observed in the plants' structures, e.g., parenchyma, collenchyma, scleren-

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chyma, different vascular systems, cambium, epidermis etc. Simple plant tissues are represented by parenchyma, collenchyma and sclerenchyma. Parenchyma is composed of cells with thin primary walls, collenchyma of cells of unevenly thickened primary cell walls, and sclerenchyma of cells having thick secondary cell walls.[22] The last type of cell is of particular importance for the bast fibre production.[3,6] Sclerenchyma fibre cells are elongated cells and they occur in different parts of plants, mainly in the stems and leaves. They can be found in ground and vascular tissues for mechanical support, but sometimes they occur in dermal tissues as well. (cf. Fig.1 and 2).[21]

In this article some attempts are given for the isolation of fibre structures from different grass and legume species and their characterisation.

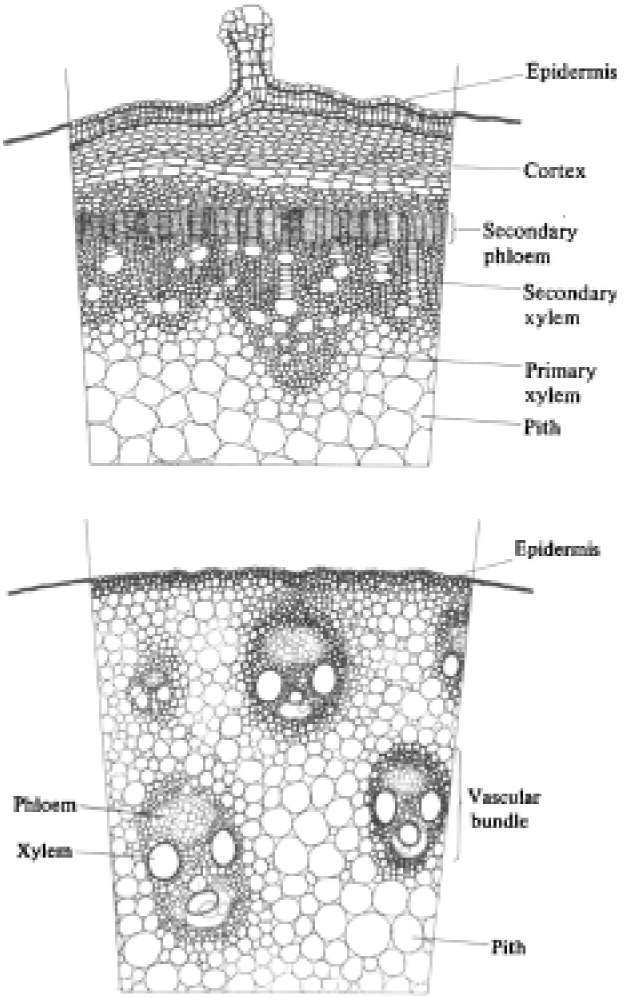


Fig. 1 – *Transverse section of a primary and a secondary dicotyledon stem and transverse section of a monocotyledon stem, respectively*[4]

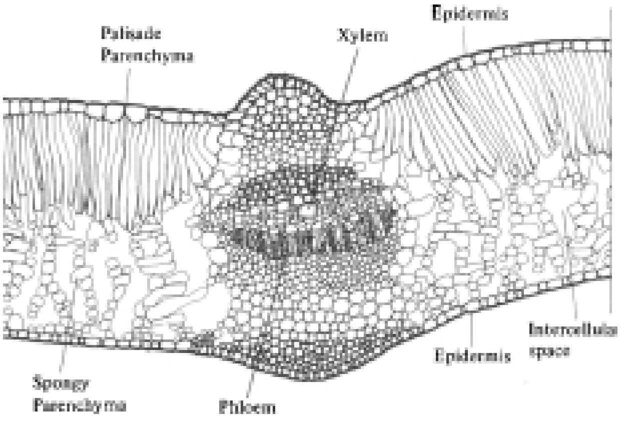


Fig. 2 – *Schematic presentation of dicotyledon leaf morphology*

Materials and methods

The elementary grass fibres were isolated from different grass sorts, i.e. Ryegrass (Lolium perenne x multiflorum), Wheat straw, Trefoil (Trifolium pratense) and Lucerne (Medicago sativa). The fibre-samples were obtained in a bio-refinery, after the liquid phase containing proteins and lactic acid was eliminated from the siled and green grasses, respectively. Different processes were used for the isolation of elementary grass fibres (cf. Table 1). Fibres were subjected to chemical treatment and microbial activity, respectively. Retting which is the process of separating fibres from non-fibre tissues in plants was performed in, both, acid and alkaline mediums respectively, and by enzymes which were developed by the microbes on the plants under wet conditions at room temperature. In this way the pectine structures connecting fibres with other plant tissues were loosened and the mechanical separation of the elementary fibres or fibre bundles could be performed. Separation of fibres was performed under wet conditions due to the very low bending rigidity of dry grasses. A Turbomat laboratory dyeing apparatus was used for the heat treatment of the plants. Different conditions of alkaline and acid treatment were tested and the optimal procedure is given in Table 1.

Table 1 – *Isolation processes of elementary grass fibres and fibre bundles*

Isolation process	Treatment	T/°C	Treatment time
Acidic hydrolyse	w = 10 % H_2SO_4	90	3 h
Alkaline treatment	w = 1 % NaOH	100	1h
Biological process	Enzymatic treatment	20	2 weeks

Analytical methods

The tenacity of the grass stems and leaves was determined in accordance with ISO norm Textile fibres – Determination of breaking force and elongation at break of individual fibres.[23] However, the breaking strength in the axial direction of the whole stems and leaves was determined in the dry state using the Statigraph Textechno M dynamometer. It was important to obtain a representative sample for testing due to the inherent variability of most biological materials and extensive mechanical damage due to the silage and pressing processes in the bio-refinery. The fineness of the grass leaves and stems was determined gravimetrically following the ISO norm Determination of linear density – gravimetric method.[24]

In addition, the geometrical and mechanical properties of the isolated elementary fibres and the fibre bundles, i.e. technical fibres obtained by different processes of grass fibres retting, i.e., separation of the fibres from the rest of the plant (e.g. acidic, alkaline and enzymatic treatment), were also studied.

A Lenzing Vibrodyn dynamometer was involved in determining the technical fibres' mechanical properties (in a wet state). The linear density of the isolated fibre bundles was determined on a Lenzing Vibroscop apparatus. The standard test method for the strain/stress determination of textile fibres and yarns according to ISO 5079 (1995),[23] was used. As mechanical and geometrical properties vary considerably according to temperature and humidity, all samples for testing were conditioned and prepared in the ISO standard atmosphere for textile testing of 65 ± 2 % relative humidity and 20 ± 2 °C.[25]

Isolated ultimate fibre cells were observed microscopically. Therefore, a Axiotech 25 HD (+pol) microscope equipped with a CCD SONY video camera, model DXC-151AP, to resolve images and a frame grabber (grey and »true colour« signal; 8 bit resolution/channel (RGB 8 : 8 : 8); image memory 3MB to digitise the image and a host computer with Kontron KS 300 (Kontron Elektronik) software for image processing, were used.[26]

Quantitative analysis was carried out in order to obtain basic quantitative data on grass fibres, such as the lengths of single or group fibres, diameters of single or group fibres. Several measurements were made in order to achieve as accurate results as possible; an arithmetical value was calculated from the obtained measurements.

Results

The mechanical properties of the Ryegrass stem and leaf measured in a dry state are collected in Tables 2 and 3. Due to grasses' history, (deformation and damage caused by the treatment of grasses in the bio-refinery, maturity grade and conditions during grass growth) the plant structures vary considerably in their properties. This inhomogeneity of samples is confirmed by very high variation coefficients when measuring. Nevertheless, the mechanical properties of the grass leaves in the axial direction are lower in comparison to the stems, although the differences are insignificant. The stress/strain behaviour of plant structures indicates a rigid characteristic with low elongation, but the high brittleness of the dry leaves and stems is especially problematic.

Table 2 – *The mean tenacity and elongation of the Ryegrass leaf*

Property	Mean value	Standard deviation	Variation coefficient %
Breaking force, N	4.83	2.84	58.65
Elongation at break, %	1.28	1.14	88.57
Tenacity, cN tex^{-1}	1.47	0.86	58.64

*Measurement conditions: temperature 20 °C, relative humidity 65 %, and test time 1.49 s

Table 3 – *The mean tenacity and elongation of the Ryegrass stem*

Property	Mean value	Standard deviation	Variation coefficient %
Breaking force, N	15.49	5.41	34.91
Elongation at break, %	1.12	0.70	62.32
Tenacity, cN tex^{-1}	1.97	0.69	34.91

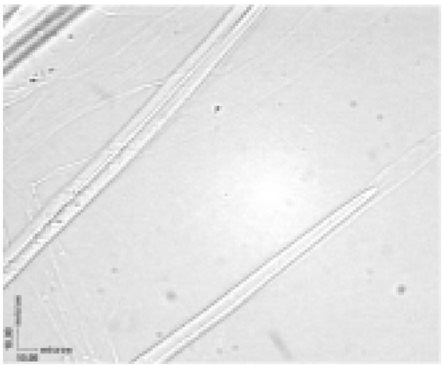
*Measurement conditions: temperature 20 °C, relative humidity 65 %, and test time 1.67 s

The fineness of the stems and leaves was determined gravimetrically and a linear density of 329 tex was obtained for leaves and 788 tex for an average stem.

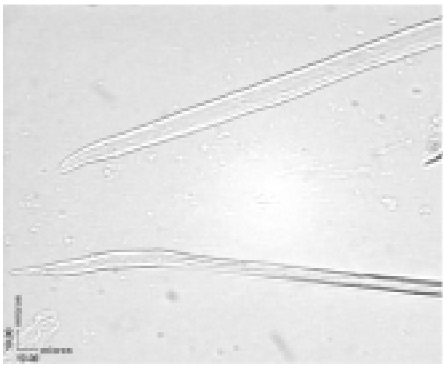
The influences of chemical and biological isolation processes on the elementary fibres were studied and the geometrical properties of the ultimate fibres were determined on microphotographs using image analysis. The longitudinal views of the fibres isolated by different procedures are given in Figures 3, 4, 5 and 6.

There were no significant differences between ultimate fibres from different origins, i.e. grass and legume species, isolation procedure or plant part

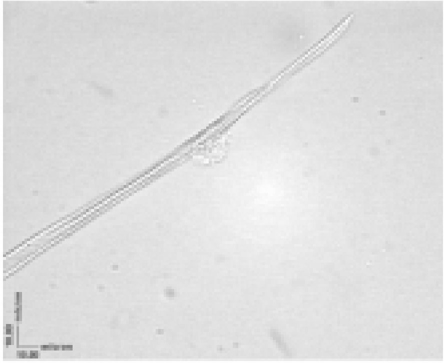
Ryegrass – leaf - NaOH treatment



Lucerne – leaf - NaOH treatment



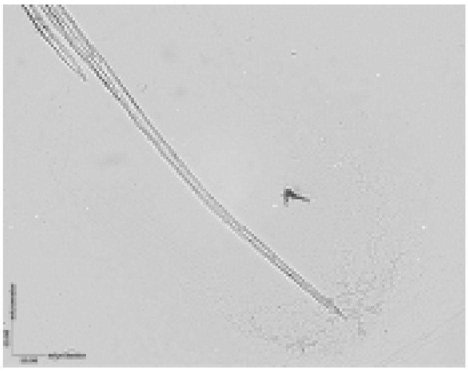
Trefoil – leaf - H_2SO_4 treatment



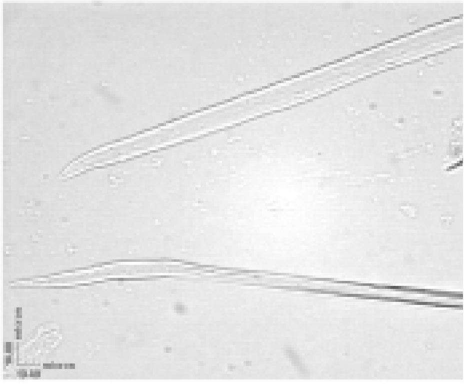
Wheat – leaf - H_2SO_4 treatment

Fig. 3 – *Ultimate fibres isolated from the leaves of Ryegrass, Trefoil, Lucerne and Wheat straw, respectively. Trefoil and Wheat fibres were isolated by H_2SO_4 treatment and Ryegrass and Lucerne by NaOH treatment.*

Trefoil – leaf- NaOH treatment



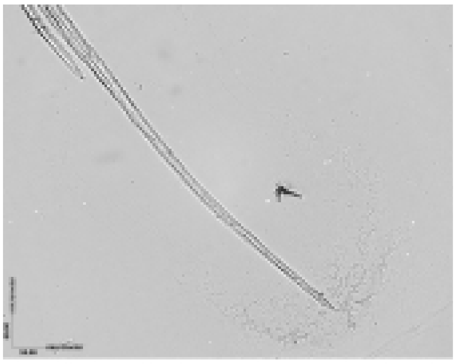
Trefoil –stem- NaOH treatment



Trefoil – leaf – H_2SO_4 treatment

Trefoil- stem – H_2SO_4 treatment

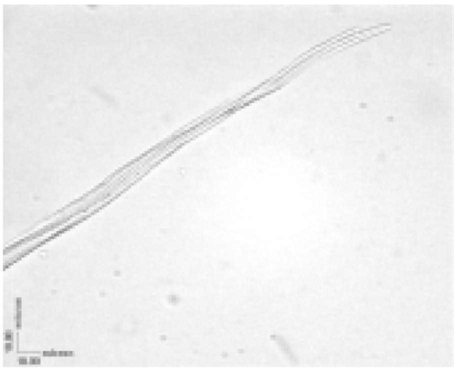
Fig 4. – *Fibres isolated by alkaline NaOH and H_2SO_4 treatment respectively*



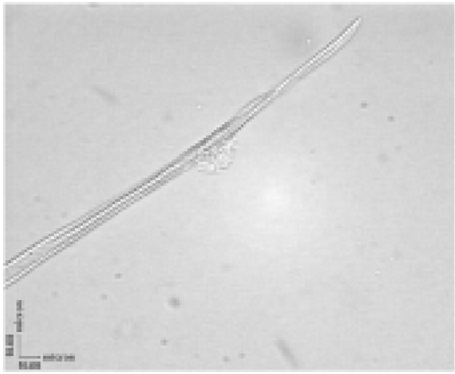
Ryegrass –leaf- H_2SO_4 - siled

Ryegrass –leaf- H_2SO_4 - green

Fig. 5 – *Fibres isolated from green and siled grasses, respectively*

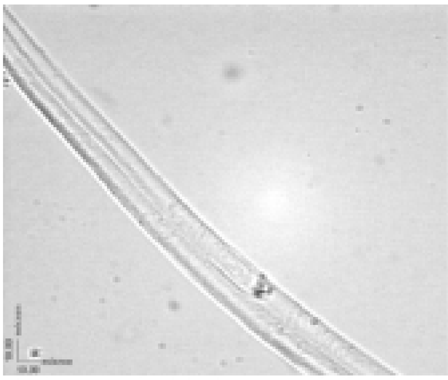


Wheat straw – leaf -H_2SO_4treatment

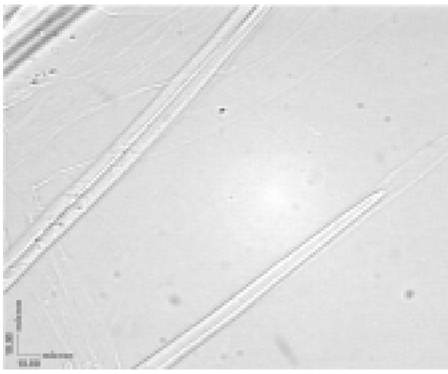


Wheat straw – stem - H_2SO_4 treatment

Fig. 6 – *Fibres isolated from stems and leaves, respectively*



Lucerne – leaf – NaOH treatment; green



Lucerne – leaf – NaOH treatment

Fig. 7: – *NaOH treated grass – fibres with damaged fibre surface*

(stem or leaf). The silage process did not influence the fibre properties. The NaOH isolation process damaged the fibre surface slightly as demonstrated in Fig. 7.

The biological and chemical procedures for leaf and stems retting, were used respectively to obtain technical grass fibres in the form of fibre bundles. However, mechanical separation of the fibre bundles was additionally needed. The fibre bundles were mainly inhomogeneous and sclerenchyma cells were often accompanied by tracheary elements (cf. Fig. 8). The breaking characteristics and fineness were oscillating strongly because of the unequal structure of the technical fibres due to the different number of fibre cells in the bundle and the addition of strange structures like conductive cells. An example of the stress/strain behaviour of those technical grass fibres isolated from ryegrass leaves is demonstrated by σ/ε curves in Fig. 9.

In Table 4 the mechanical properties of the grass and legume fibre bundles of different pre-treatments and origin, are compared (green, siled, bio-refinery: once or twice pressed, technical fibres from leaves and stems). Technical fibres were isolated by biological retting and tested on a dynamometer in a wet state. It was impossible to measure the dry fibres due to their very high brittleness.

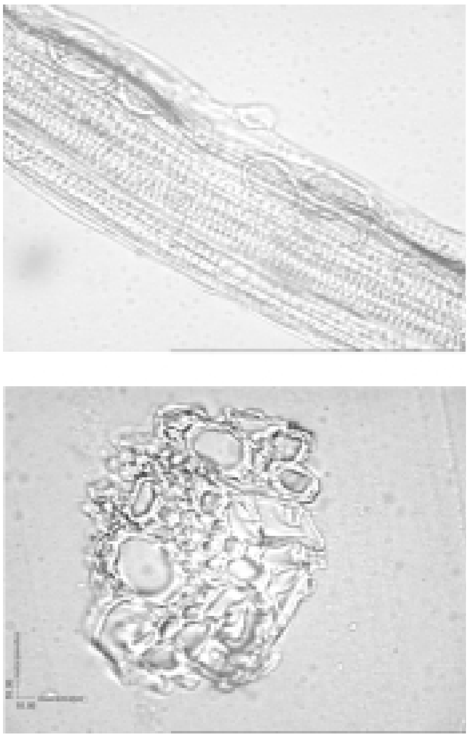


Fig. 8 – *The longitudinal and transverse views of an enzyme retted technical grass fibre*

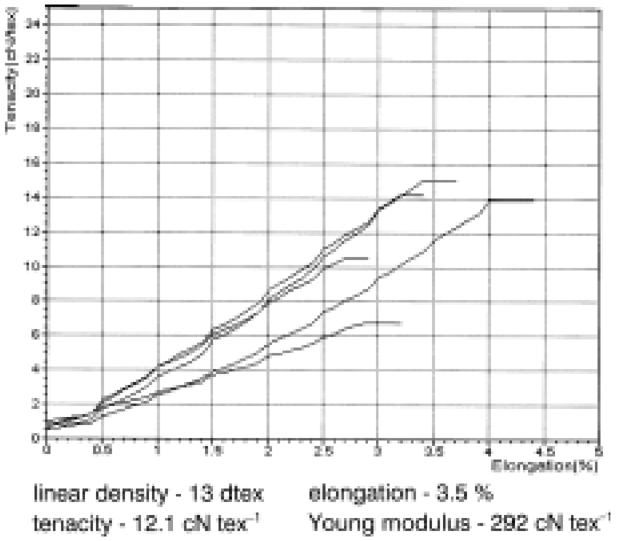


Fig. 9 – *σ/ε curves of technical fibres isolated from ryegrass leaves by enzyme procedure*

A slight tendency for higher tenacity of stem fibres is observed, although due to the very intensive variability of samples unique model could not be established. Elongations of samples at break are rather low, but higher than in the case of whole stems or leaves. The elongations vary between 1.5 to 5.5 % and tenacities from 7.5 to 21 cN tex^{-1}. The obtained values are comparable with the mechanical properties of some textile bast fibres, e.g. jute, hemp or coir. Ultimate fibre cell in hemp is 13 – 26 mm long; its diameter is between 5 and 32 μm, tenacity 29 – 47 cN tex^{-1} and elongation 1.8 %.

Table 4 – *Mechanical properties of grass and legume fibre bundles of different pre-treatments and origin (green, siled, bio-refinery: once or twice pressed, technical fibres from leaves and stems)*

Grass species	Linear density dtex	Tena- city cN/tex	Elon- gation %
Trefoil – green – once pressed- stem	105	20.1	3.0
Trefoil – green – once pressed- leaf	22	9.7	4.5
Trefoil – siled – twice pressed – stem	44	21.4	2.8
Trefoil – siled – twice pressed – leaf	20	6.8	3
Ryegrass-green – once pressed – stem	52	11.4	1.3
Ryegrass-green – once pressed – leaf	15	12.9	4.0
Ryegrass-siled – once xpressed – stem	36	21.4	1.7
Ryegrass-siled – once pressed – leaf	13	12.1	3.5
Lucerne – green – once pressed- stem	48	13.7	1.5
Lucerne – green – once pressed – leaf	31	7.5	5.7
Lucerne – green – once pressed – stem	65	13.3	2.1
Lucerne – green – twice pressed-leaf	20	13.1	4.9
Wheat straw- green – once pressed- stem	46	9.1	4.6
Wheat straw- green – once pressed- leaf	38	16.1	1.5

The geometrical characteristics of ultimate fibres and mechanical properties of technical grass fibres are summarized in Table 5. The length of the elementary cells in grasses and legumes is between 0.5 and 3 mm, slightly shorter fibre cells are present in leaves when compared to the cells from stems. The diameter of the isolated fibres is approximately 15 – 18 μm.

Conclusion

The utilization of green biomass has attracted much attention recently, due to the growing awareness regarding sustainable development. In response to these requests some renewable resources like green biomass (grass) have been tested as to whether they could be utilized in a new innovative way. Grass because of its extensive availability represents a great potential.

Separation of fibres from the rest of the plant is required for any employment of grass fibres. Chem-

Table 5 – *Geometrical and mechanical properties of ultimate and technical grass fibres*

Grass species	Unit	Ryegrass	Wheat grass	Trefoil	Lucerne
Length of the elementary fibres in grass stem	μm	900-1100	800-1300	2100-3200	1200
Length of the elementary fibres in grass leaf	μm	400-700	1300	600-1000	600-1300
Linear density of the fibre bundles	dtex	12-100	37-45	20-105	19-65
Tenacity of the fibre bundles	cN tex^{-1}	6-21	9-17	6-21	7-14
Elongation of the fibre bundles	%	1-5	1-5	2-4.5	1-6

ical and biological retting, (acidic, alkaline and enzymatic treatment) enables the mechanical isolation of grass fibres. It is shown, that in comparison to the acid hydrolytic decomposition of the pectin structures, the alkaline treatment causes some surface damages on isolated fibres, but enzyme treated fibres are of good quality. However, the mechanical separation of the fibre structures from the retted stems or leaves is only possible on wet plants due to the very high dry grass brittleness. The mechanical properties of isolated grass fibre bundles are inferior to the properties of conventional textile bast fibres. Due to the very low bending tenacity and the high exacting isolation process, the utilization of grass is only reasonable in the form of whole stem or leaf for some technical applications (e.g. insulation, nonwoven textiles, etc).

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