Appendix A

Lyocell end-use development datasheets

The following datasheets are presented with the kind permission of Acordis Fibres.

But for changing the fibre name from 'Courtaulds Lyocell' to 'Acordis Lyocell' or 'Tencel' they are the original documents prepared by Mr Manny Coulon, Ms Pam Johnson, Mr Robert Morley, and Mr Calvin Woodings for launching lyocell into the technical textiles, nonwovens, and special paper markets between 1996 and 1998.

They cover the following properties of lyocell in the end-uses mentioned.
Technical textiles:

1 Tensile and tear strength
2 Dimensional stability
3 Heat ageing
4 Abrasion resistance
5 Drape and fluidity
6 Moisture
7 Fibrillation

Nonwovens:

8 Web bonding – Hydroentanglement
9 Web bonding – Needling
10 Web bonding – Latex
11 Wet-laying
12 Air-laying
13 Wipes
14 Medical swabs and gauzes
15 Absorbency
16 Chemical and UV resistance
17 Biodegradation

Special papers:

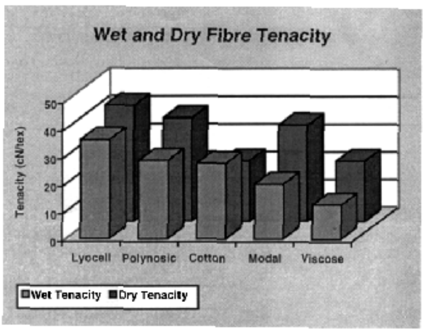
18 100% Acordis Lyocell papers
19 Blends
20 Filtration

N.B. The 'Acordis Lyocell' brand has been dropped. Acordis's lyocell fibre is now branded Tencel® in all markets.

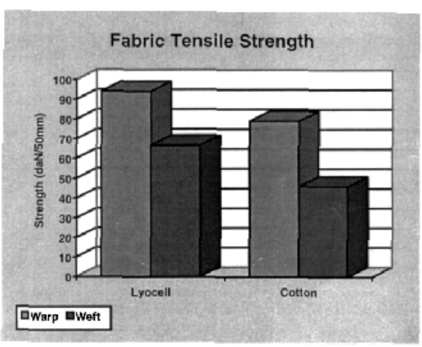
Tensile and Tear Strength

Whether TENCEL® fibre is wet or dry, its strength exceeds that of cotton and is in fact stronger than all other cellulosic man-made staple fibres. Its compatibility with polyester means that blends with TENCEL® form yarns of similar strength to 100% polyester. Resulting fabric strengths can be exceptional, particularly in respect of tear resistance.

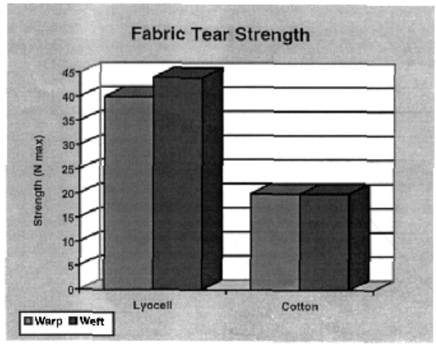
The dry tenacity of TENCEL® is up to 44 cN/tex (5 g/den), considerably greater than other cellulose fibres. Even when wet, this highly moisture absorbent fibre will retain up to 80% of its strength. Of course, when dried, the original fibre strength is recovered.



This high fibre strength translates into high tensile strength in the spun yarn. In finished fabrics, TENCEL® can easily give a 25% tensile strength advantage over cotton.

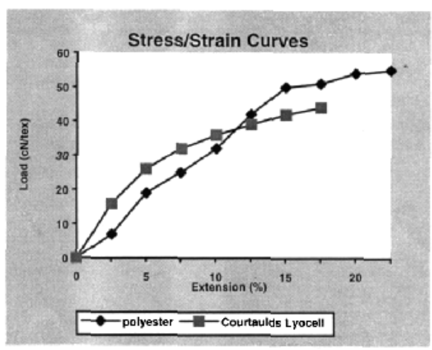


The tear strength performance is even more impressive: tear strengths can double that expected for a similar cotton fabric, depending upon the fabric construction used.

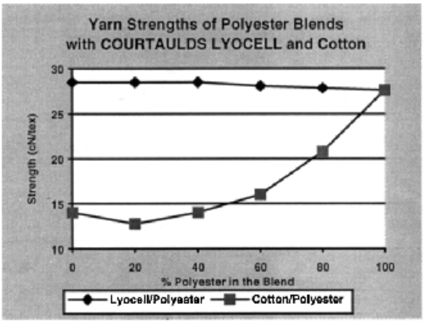


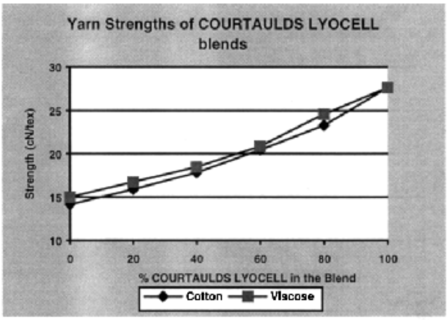
Blends with polyester

TENCEL® blends particularly well with polyester. The stress / strain curves for both fibres are compatible, such that yarns of high strength are possible.



In combination with polyester, yarn strengths, and therefore fabric strengths, are comparable to 100% polyester at all blend levels with TENCEL®.





This means that the proportions of each fibre used in a polyester blend with TENCEL® can be adjusted to meet other performance requirements whilst still maintaining optimum strength. For instance, high compatibility with polyester allows freedom to balance the abrasion resistance offered by the polyester with the absorbency and comfort brought by the TENCEL®, and without compromising the fabric tensile properties.

Polyester blends with cotton give inferior strength. Even with 30% polyester in blend with cotton, yarn strength is no greater than for 100% cotton. This is because the stress/strain curve of cotton is a poor match to polyester, whilst that of TENCEL® is highly compatible with polyester.

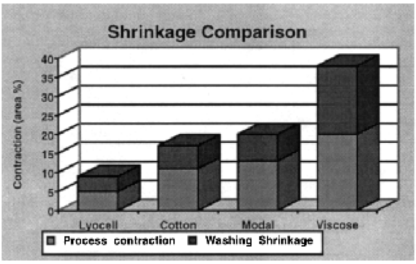
A blend of TENCEL® with cotton or viscose also yields improvements in yarn strength. Strength increases are achieved in almost direct proportion to the percentage of TENCEL® fibre added to the blend.

TENCEL®, either as 100%, or in blend with polyester produces strong yarns which translate into excellent fabric tensile and tear strength. The absorbency of TENCEL® results in fabrics which are comfortable to wear and perform well in demanding applications.

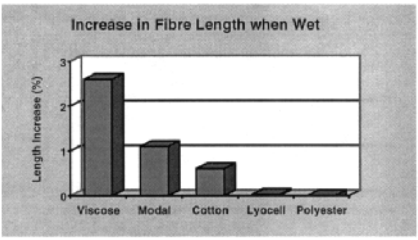
Dimensional Stability of Woven Fabrics

Woven fabrics produced from TENCEL® fibre have excellent stability both in processing and in use. Resin free fabrics give lower shrinkage in laundering than comparable cotton fabrics and do not show the progressive shrinkage problems often associated with cotton and other cellulosic fabrics.

Wet Stability - The superior wet stability of TENCEL® is due to its high wet modulus and, to a lesser extent, its low linear swelling in water. Fabrics from TENCEL® can produce smaller losses in area during wet processing as well as low laundering shrinkages in use. Combined processing and shrinkage losses can be better than half that for cotton and other cellulosics. TENCEL® fabrics can achieve stable dimensions rapidly when wet, and still offer lower residual shrinkage.

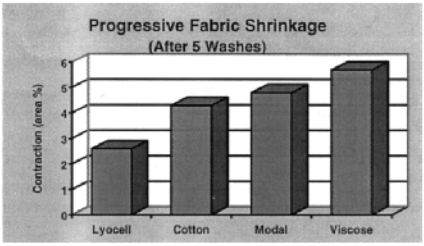


Such dimensional stability is not unusual for TENCEL®, even without the use of resins if fabrics are relaxed correctly in finishing.



The basis for the inherent stability of TENCEL® is that its fibres do not change in length when wet. All other cellulosic fibres grow in length when wet, which means that for every wet/dry cycle there is potential for progressive shrinkage as the fibres alternately extend in length and then contract.

If required, the good dimensional stability of TENCEL® fabrics can be enhanced still further by the use of suitable resins or by blending with a synthetic fibre such as polyester or nylon.



TENCEL® fibre is stiffer than other cellulosics when wet. Fibres with low wet stiffness will easily distort during wet processing which can lead to shrinkage problems. Low wet modulus is one cause of such shrinkage problems with viscose and is also a contributing factor in the progressive shrinkage of cotton. Progressive shrinkage is accepted as a characteristic feature of cotton but is typically negligible in fabrics made from TENCEL®.

Fibre Tensile Moduli Compared to Other Cellulosics

	TENCEL®	Polynosic	Modal	Cotton	Viscose
Dry cN/tex	1113	-	717	500	371
Wet cN/tex	265	210	125	150	53

Dry Stiffness - TENCEL® fibre has a dry tensile modulus comparable to polyester and is resistant to stretching. This high fibre stiffness means that appropriately finished fabrics are stable under load and will resist distortion better than nylon.

Fibre Tensile Moduli Compared to Synthetics

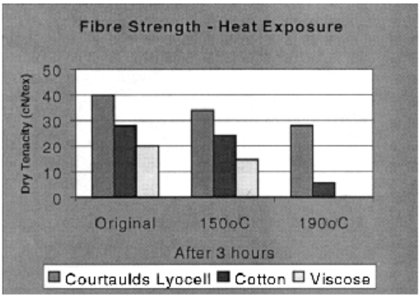
	TENCEL®	HT polyester	HT nylon
Dry (cN/tex)	1113	1014	500
Dry (GPa)	16	14	6

Heat Ageing

In addition to having a higher initial strength, TENCEL® outperforms cotton in its ability to retain fibre strength when subjected to elevated temperatures. In suitably engineered structures, TENCEL® can withstand higher temperatures over longer periods than cotton or viscose.

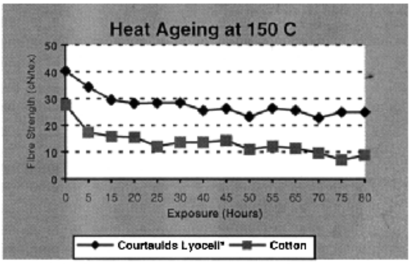
TENCEL® fibres do not melt and are stable below 150°C. Above 170°C the fibres start to lose strength gradually, beginning to decompose more rapidly by 300°C. At 420°C the fibres will ignite. Under controlled conditions they can be oxidised and carbonised.

Cellulosic fibres are not well known for their thermal resistance or thermal stability. However, TENCEL® exhibits better resistance to dry heat at 150°C than cotton and viscose fibres.



The strength benefit of TENCEL® is also apparent after three hours exposure to 190°C. The strength of viscose and cotton fibres are reduced by over two thirds. In comparison, TENCEL® loses less than one third.

After 80 hours exposure at 150°C, TENCEL® remains as strong as the unexposed cotton fibre.



The strength advantage of TENCEL® was maintained throughout the test, which was extended to over 1000 hours.

TENCEL® discolours significantly less than viscose and cotton fibres, when exposed to temperatures above 120°C for extended periods of time.

Abrasion Resistance

In line with other cellulosics, the abrasion performance of TENCEL® is sufficient for the general needs of apparel. For more demanding uses in industrial and technical applications, enhanced abrasion resistance may be required. Practical options include blending with low proportions of synthetic fibre or application of special finishes or resins. Such fabrics can retain many of the desirable features of 100% TENCEL®

20% Blends with polyester or nylon

Blends with synthetic fibres can provide a considerable improvement in the abrasion performance of TENCEL® fabrics. Substitution of 20% polyester doubles the Martindale abrasion resistance to 35,000 cycles for a typical 200g/m^2 fabric. Blending with 20% nylon in a similar fabric construction has raised the Martindale abrasion level to more than 100,000 cycles.

	100% TENCEL®	80:20 blend TENCEL® / polyester	80:20 blend TENCEL® / nylon
Martindale cycles	15,000	35,000	100,000+

Blending with 20% of a synthetic fibre produces fabrics which retain much of the original character and physical performance benefits of 100% TENCEL® fabrics.

Synthetic blend levels of 20% and below are not considered to present a hot melt hazard in next-to-skin applications provided that fibre blends are used rather than yarn on yarn mixing.

TENCEL® fabrics that also contain synthetic fibres can be cross dyed to solid shades if required. However, TENCEL® fabrics with up to 20% polyester or nylon can give attractive marl effects where only the lyocell fibre has been dyed.

10% Blends with nylon

Using even lower blending levels of synthetic fibre, significant performance benefits are still possible. With only 10% nylon in an intimate blend, Martindale abrasion performance can be raised to over 60,000 cycles for a 200g/m^2 fabric.

	100% TENCEL®	90:10 blend TENCEL® / nylon	80:20 blend TENCEL® / nylon
Martindale cycles	15,000	66,000	100,000+

Use of Fabric Finishes

Abrasion resistance can also be improved by the use of suitable fabric finishes.

For example, the application of an Axis treatment to TENCEL® fabric results in a small but worthwhile improvement in measured abrasion performance.

	100% TENCEL® (without resin)	100% TENCEL® (Axis finish)	100% TENCEL® (Perapret HVN)
Martindale cycles	15,000	20,000	29,000

Abrasion performance can be increased still further by the use of a resin binder. By applying 100g/l Perapret HVN, the abrasion resistance of 100% TENCEL® fabric can be raised to 29,000 Martindale cycles (again, for a 200 g/m^2 fabric). Although such finishes tend to stiffen the fabric, the natural drape and fluidity of TENCEL® means that the final handle is still softer than for other cellulosics without a finish.

Drape and Fluidity

Fabrics in TENCEL® are characterised by their unique drape and fluidity. Such tactile properties are a direct result of the space created within the fabric when it is prepared, dyed and finished. The spaces between the warp and weft yarns allow the fabric to drape well and the ease with which the yarns can move relative to one another gives the impression of fluidity in the fabric.

Loomstate fabrics in TENCEL® are similar to other loomstate fabrics in terms of stiffness, due to the presence of size and the frictional forces between the yarns. However, after wet processing, the handle of the fabric changes significantly: the fabric develops better drape and a fluidity that clearly differs from other fabrics. Hence, the fluidity and drape are related to changes that take place during wet processing of the fabric.

What happens during wet processing?

When TENCEL® fibre is wetted it absorbs water and the fibre diameter increases by about 35%, but the fibre length does not change.

Figure 1 - greige fabric

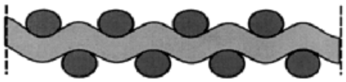


Figure 2 - wet fabric

Figure 3 - dried fabric

When a greige fabric (Figure 1) in TENCEL® is wetted, the swelling of the fibres/yarns causes an increase in the crimp of the yarn but without an increase in the length of the yarn (Figure 2). Therefore, the distance between the extremities of the ends of the yarn in the fabric must decrease to accommodate the increase in yarn crimp. The fabric dimensions therefore decrease, i.e. the fabric shrinks.

When the fabric is dried the fibres/yarns reduce in diameter back to their original size (Figure 3) but the dimensions of the fabric are not recovered, therefore the fabric remains in the "shrunk" state. This means that space is created around each yarn in the fabric as a result of the wet treatment and subsequent drying. The more a TENCEL® fabric is wetted and dried, the more the fibres and yarns will take up the new configuration of the wet fabric. Fibre movement occurs within the yarns as the fibres reduce in diameter during drying. Fabric treatment processes that involve a number of wetting and drying cycles are therefore very effective in creating space between yarns.

The creation of space between the warp and weft yarns increases the bulk of the fabric and allows the yarns to move easily relative to each other. This ease of movement within the fabric produces both the drape characteristics and the sense of fabric fluidity.

Why other fabrics behave differently

- TENCEL® yarns are very lean, so there is little space within the yarn for the fibres to swell into. The yarn diameter therefore increases significantly when it is wetted. The yarns return to their lean state after the wetted fabric has been dried, so space is created around the yarns rather than within the yarns.
- Other fibres and yarns retain their bulk after wetting and drying, and this reduces available space that has been created around the yarns. There is therefore a greater force between the yarns to limit their movement. Some other cellulosic fibres also give lean yarns but they are not robust enough to withstand the wetting and drying processes required for "space creation".
- Synthetic fibres are generally hydrophobic and therefore do not absorb water. Space cannot therefore be created by the swelling and contraction of the fibres as they are wetted and dried.

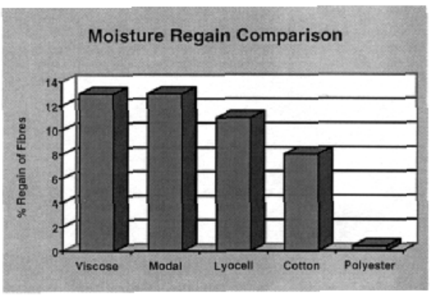
To generate drape and fluidity

- Fabric must be allowed to shrink during wet processes
- Tensioning of the fabric should be minimised during wet processing and stentering.
- Dry beating and tumble drying the fabric will enhance drape and fluidity.
- The use of lubricants can help to generate drape and fluidity.
- Increasing the bulk of the yarns will not enhance drape and fluidity.

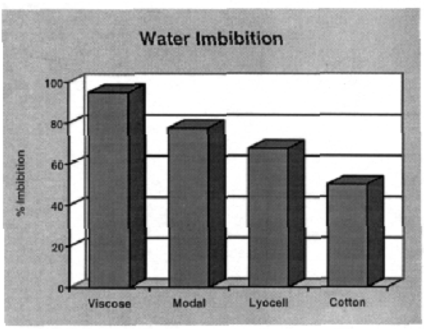
Moisture Properties

In common with other cellulosics, TENCEL® absorbs water readily to give excellent wearer comfort. Moisture absorbency is combined with an inherently high strength capability to provide a combination of properties that is unusual, if not unique in a cellulosic man-made staple fibre. Absorbency may be enhanced further by using the fibrillating capability of TENCEL®.

The moisture absorbency of TENCEL® fibre is high, and this means that fabrics made from it provide the kind of wearer comfort normally associated with natural fibres such as cotton.

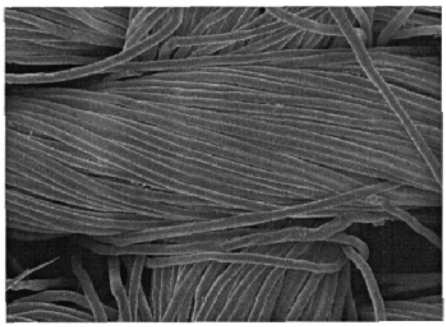


The natural moisture regain of TENCEL® is slightly higher than for cotton and much greater than for synthetic fibres such as polyester. This helps to ensure static free handling of TENCEL® fibres, yarns and fabrics, both in processing and in use.

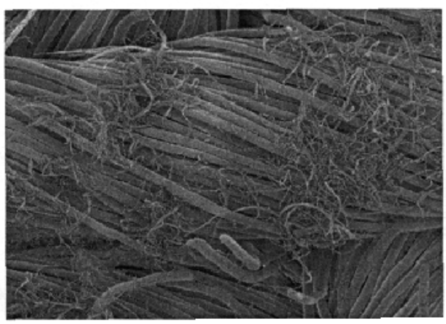


Another measure of water absorbency of a fibre, imbibition, again shows that, TENCEL® can be more absorbent than cotton.

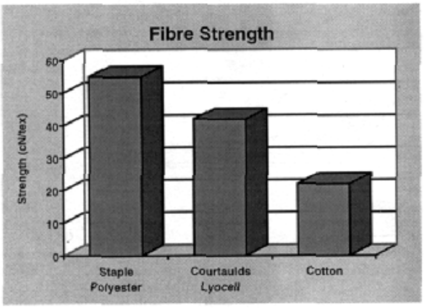
The total moisture absorbency of a fabric made from any cellulosic fibre also will depend on the physical structure, as well as the accessibility of the cellulose. In the case of TENCEL® the physical structure of the final fabric can be modified during wet processing to create surface microfibrils. These fibrils provide an increase in the surface area available for water absorption. This fibrillation capability offers the potential for features normally only available from expensively produced synthetic microfibres.



Surface of fabric without fibrillation



Fibrillated fabric surface

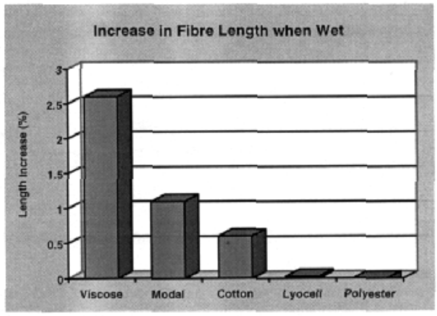


High strength together with good moisture absorbency are an unusual combination in any fibre. TENCEL® provides both in good measure, whilst cotton has a lower strength, and polyester provides the strength but not the absorbency required to give wearer comfort.

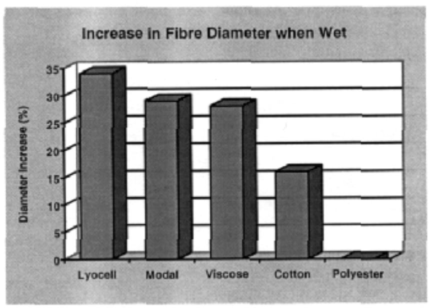
TENCEL® retains over 80% of its inherent fibre strength when wet. Full strength is of course recovered when dried again.

The fibre has a high moisture absorbency and yet still has low shrinkage both in processing and in use (see Technical Textiles 6 datasheet). This stability draws from the relatively high fibre stiffness and the fact that the length of a TENCEL® fibre is completely unchanged when wetted or dried.

In comparison, other cellulosic fibres become considerably swollen in length when wet which contributes to potential shrinkage problems in fabrics made from them.



Although the length of a TENCEL® fibre is unaffected by moisture, there is significant swelling in fibre diameter. Indeed, where required, fibre and yarn swelling can be used to close up the spacing between yarns within a fabric in applications such as barrier fabrics, filters and water repellent products.



Fibrillation

TENCEL® can be fibrillated to develop interesting aesthetic effects that can also have practical benefits in technical and industrial applications.

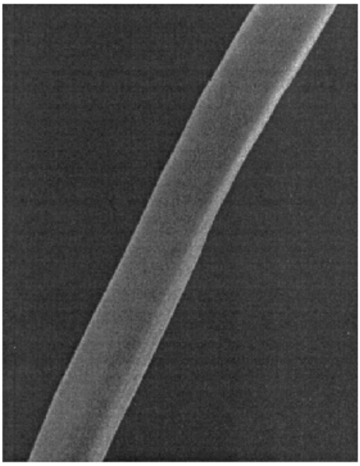
Fibrillation is the longitudinal splitting of a single fibre into microfibres of typically less than 1 to 4 microns in diameter. The splitting occurs as a result of wet abrasion against fabric or metal. The fibrils are so fine that they can become almost transparent, giving a white or 'frosty' appearance to finished fabric. In cases of extreme fibrillation, the micro-fibrils can become entangled, giving a pilled appearance.

Using fibrillation

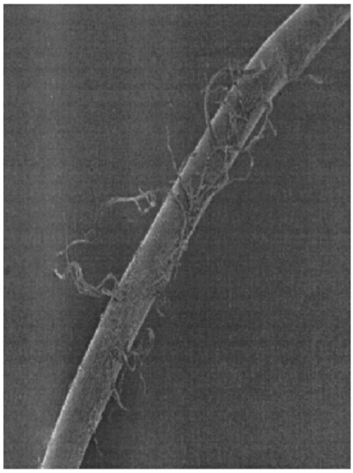
Fibrillation can occur in the wet processing of fabrics and garments made from TENCEL®. The microfibres generated can be used to create a variety of interesting tactile aesthetics. A peach skin effect, which can also withstand repeated domestic washing at 40°C is possible, providing that the fibrillation is developed such that the fibrils cannot become long and entangled. This is key.

Fibrillation can be used in both piece dyeing of fabric and in garment washing/dyeing to produce characteristic soft and drapey aesthetics.

Unfibrillated TENCEL®

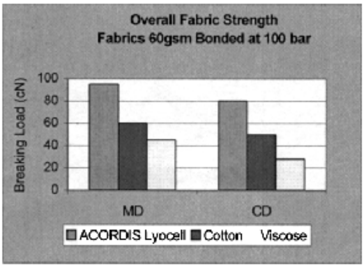


Fibrillated TENCEL® fibre



Web Bonding - Hydroentanglement

ACORDIS LYOCELL exhibits good hydroentanglement efficiency, having good aperturing clarity, and providing strong, stable, low linting, soft absorbent fabrics over a wide range of pressures. Hydroentangled ACORDIS LYOCELL fabrics are significantly stronger than those produced from other cellulosic fibres. By using lower decitex ACORDIS LYOCELL, strength, absorbency and handle of hydroentangled fabrics can be further improved.



ACORDIS LYOCELL is ideally suited to the hydroentanglement process. The fibre's high wet and dry strength can be translated into high fabric strengths, with the added opportunity to generate fibrillation using this process.

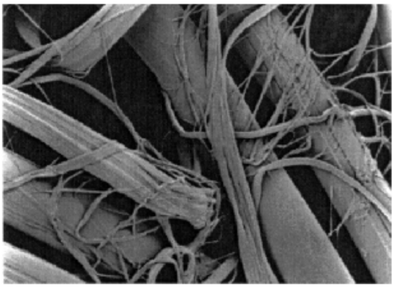
Plain and apertured hydroentangled fabrics can be produced using ACORDIS LYOCELL down to 20gsm. Strong stable fabrics can be made at a range of pressures without the use of binders. When bonded at low pressures, lyocell fabrics are exceptionally soft, have an attractive, silky appearance and particularly good drape characteristics.

ACORDIS LYOCELL fibres can be fibrillated by using bonding pressures over 120 bar.

Fibrillation can alter fabric properties significantly, depending upon the fabric construction - opacity, wicking, wiping performance, strength, and barrier performance can all be improved.

Low levels of fibrillation do not increase fabric linting, as the fibrils remain attached to the fibre.

Fibrillated ACORDIS LYOCELL fibres



The abrasion and delamination resistance of hydroentangled lyocell fabrics can be improved by blending with nylon or polyester. Superior, high strength, bulky, porous and absorbent coating substrates, having a smooth surface, particularly suitable for use in artificial leathers can be made.

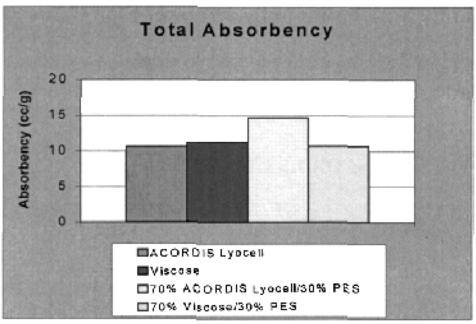
Durable fabrics with a more textile like appearance are also possible by manipulation of the bonding conditions used. High pressure bonding of ACORDIS LYOCELL fibres has produced fabrics of comparable strength to equivalent weight woven cotton.

ACORDIS LYOCELL has been found to have excellent aperturing and embossing clarity compared to other cellulosic fibres used in hydroentanglement, making excellent fabrics for gauzes and wipes.

ACORDIS LYOCELL can be readily used in blends with viscose to improve both wet and dry strengths of hydroentangled nonwovens. Blends with polyester have also produced highly absorbent products.

ACORDIS LYOCELL has similar absorbency to viscose fibre, but this is significantly improved when blended with polyester. This is primarily due to the higher resilience of lyocell fibre, which does not suffer from wet collapse as viscose does.

As with any fibre, some optimisation of fibre type, blend ratio and pressure profile will be required to achieve the desired parameters. Lower decitex variants such as 1.4 can offer improved strength, softness and absorbency over 1.7 decitex fibres, for the same basis weight and bonding conditions.



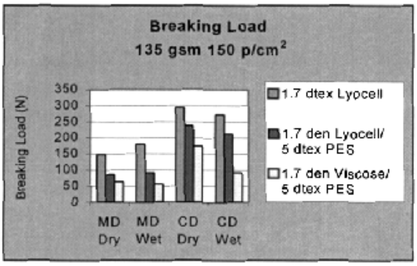
Because of the solvent spinning process, ACORDIS LYOCELL is a remarkably pure form of cellulose. After *hydroentanglement* ACORDIS LYOCELL has been found to have lower levels of cations and anions than other cellulosic fibres, making it suitable for products such as high performance clean room wipes.

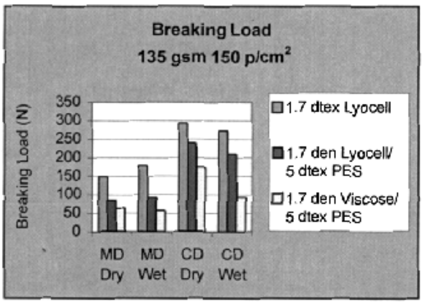
Hydroentangled ACORDIS LYOCELL now has US FDA 510K covering its use in sensitive medical applications, where its strength, absorbency, low linting, precise aperturing and disposability are key features. Unlike its synthetic counterparts, lyocell products are completely biodegradable.

Web Bonding - Needling

ACORDIS LYOCELL fibres give stronger and more stable needlefelts than viscose. Needled ACORDIS LYOCELL webs are more resistant to wet collapse than viscose equivalents and can form more open, bulky structures with a higher absorbent capacity.

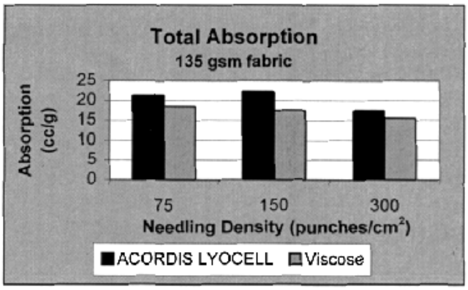
At moderate needling densities, ACORDIS LYOCELL needlefelts are markedly stronger and more stable than viscose equivalents. This is illustrated by the tensile and burst strength data below, which particularly highlight the strength retention of ACORDIS LYOCELL when wet.





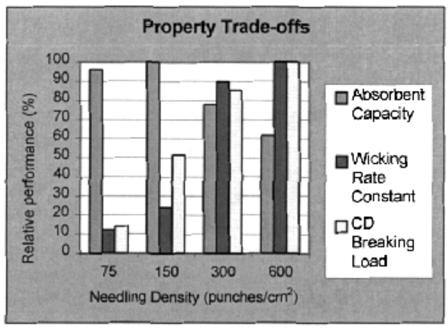
ACORDIS LYOCELL is so strong that it can easily be used at finer counts. In trials, fabrics made from 1.7 dtex ACORDIS LYOCELL were over twice as strong as viscose when dry and three times as strong when wet. ACORDIS LYOCELL can also boost the strength of cellulosic/polyester blends.

Higher strength can be valuable in itself, but also offers the potential to make lighter products or to reduce the level of non-absorbent binding materials.
ACORDIS LYOCELL which forms more open, bulky needlefelt structures than comparable viscose fibres can *help increase total absorbent capacity.*



The high wet modulus of ACORDIS LYOCELL also leads to improved wet resiliency. Needlefelts made from 1.7 dtex ACORDIS LYOCELL show only half the wet collapse of equivalent 3.3 dtex rayon structures. This is clearly advantageous in applications where liquid retention is important.

The balance of strength, absorption rate and capacity can be further manipulated for a particular end-use by the choice of appropriate needling parameters.



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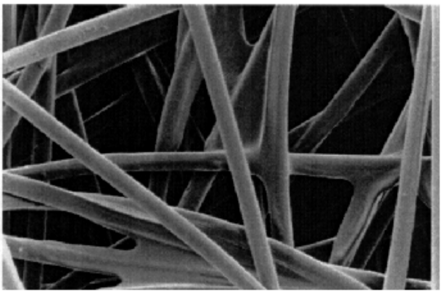
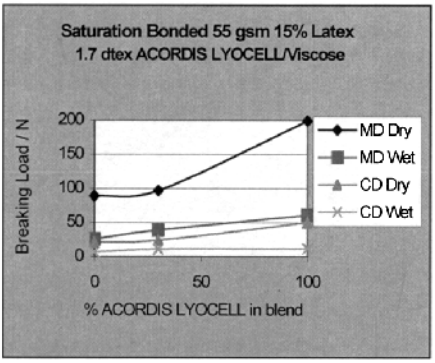
Web Bonding - Latex

Replacing viscose with ACORDIS LYOCELL in latex bonded fabrics doubles dry strength and gives an even greater improvement in wet strength. This opens up opportunities for stronger or lighter products, or reduced binder levels for greater absorbency.

Latex bonded ACORDIS LYOCELL



In saturation bonding, ACORDIS LYOCELL gives twice the dry fabric strength of viscose rayon and an even greater improvement in wet strength.

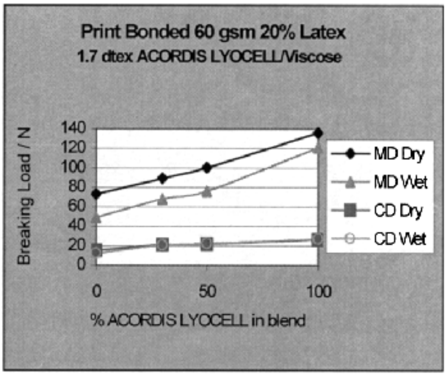


This improved strength offers various opportunities. Fabrics can be made stronger. Alternatively products can be made to current strength specifications, but at lower basis weight or with reduced binder levels. Lower binder levels create the potential for increased absorbency and better fabric aesthetics.

Because ACORDIS LYOCELL has a higher fibre modulus than viscose rayon, the resulting saturation bonded fabrics are stiffer than when viscose is used under the same bonding conditions. This may be beneficial in some end uses, e.g. interlinings.

If greater drape and softness is required, the use of a softer (lower Tg) latex is recommended to achieve the optimum balance of fabric aesthetics and performance.

Similar effects can be achieved in print bonded fabrics, e.g. for household wiping applications. Partially replacing viscose with ACORDIS LYOCELL boosts strength, opening the way for stronger, lighter or more absorbent products.



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Wet Laying

ACORDIS LYOCELL is produced as a tow, which is parallel and twist-free. In this form it is ideal for precision cutting to short fibre lengths for wet-laid nonwovens, allowing clean, uniform webs to be produced.

ACORDIS LYOCELL can be dispersed easily in water. The fibre has a relatively high modulus, so long lengths can be used for wet-laying, allowing very strong webs to be produced by this route. ACORDIS LYOCELL has been successfully wet-laid up to 16mm, although the fibre does need a high degree of dilution at such long staple lengths.

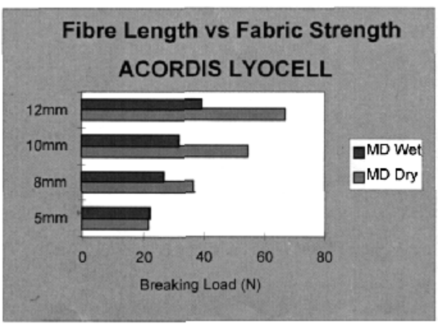
The circular cross-section of lyocell fibres produces a large amount of inter-fibre contact, resulting in a high wet web cohesion and making transfers of the web prior to bonding much easier.

ACORDIS LYOCELL has a low water imbibition which allows easier drying of wet fabrics whilst the fibre's high wet stability results in reduced fabric shrinkage losses.

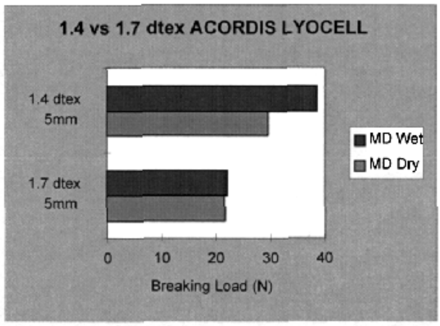
The fibre can be fibrillated by vigorous mixing of the slurry in a hydrapulper or similar mixer. Fibrillation adds strength to the web, which can then be processed as a paper. Alternatively, bonding can be carried out by hydroentanglement, where, again, fibrillation can be induced if so desired.

Fibrillation dramatically increases the mean length to diameter ratio, and agglomeration will result if fibres are close to the critical length and concentration.

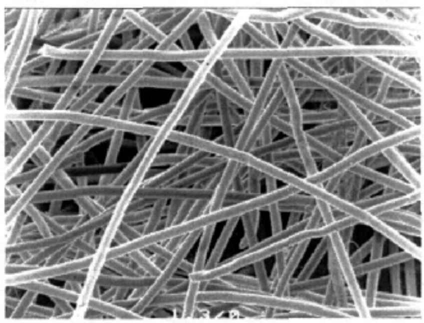
Hydroentangled wet-laid lyocell webs produce strong fabrics. Further significant strength improvements can be achieved by increasing the fibre length: fabric produced from 12mm lyocell has three times the dry tensile strength of 5mm fabric.



Decreasing fibre from 1.7 to 1.4 dtex, also produces significantly stronger wetlaid nonwovens by increasing the number of fibres within the fabric. The 1.4 dtex wet-laid nonwoven also exhibits significantly higher wet than dry strength.



Further strength improvement is possible by using longer length 1.4 dtex fibres.

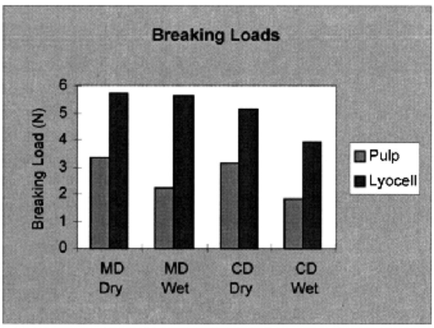


Air Laying

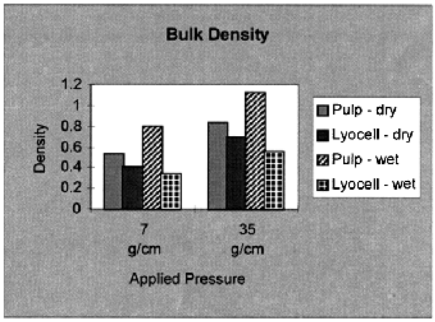
ACORDIS LYOCELL tow can be precision cut to short fibre lengths, either crimped or uncrimped, which are ideal for air-laying. Inclusion of the fibre in air-laid pulp products can improve bulk, softness, absorbent capacity and strength.

The importance of air-laying as a technology is growing significantly, with more sophisticated products and demanding applications being introduced. This extends the opportunity for using new fibres in addition to woodpulp, in order to achieve the desired fabric properties. As ACORDIS LYOCELL is manufactured as a tow product, it can be cut to short lengths suitable for air-laying processes. Additionally, there exists the possibility to use crimped or uncrimped fibre the choice depending upon the process detail and fabric properties required. A range of fibre decitexs is available, and fibre finish can be tailored to suit the specific process requirements.

Results from fabrics produced using flat-bed air-lay technology demonstrate the benefits of using ACORDIS LYOCELL fibre in air-laid structures. In a series of trials 4mm crimped ACORDIS LYOCELL was used as a replacement for pulp in a 80 gsm fabric with 20% bicomponent fibre (included for bonding purposes). The length of the lyocell fibres and excellent strength properties result in a significant strength improvement, especially when wet - where the fabric containing ACORDIS LYOCELL shows a doubling in strength.



The use of ACORDIS LYOCELL also results in an improvement in bulk properties. Dry results show the fabric including lyocell to be thicker (lower bulk density). Lyocell also shows superior resiliency when wet, indicated by the smaller increase in density compared to pulp.



This improvement in bulk and resiliency leads also to an increase in total absorptive capacity. The fabric containing lyocell has a total absorption of 21.9 cc/g - an improvement of around 50%. Panel testing used to evaluate fabric softness shows a significant improvement in fabric hand when lyocell was used. ACORDIS LYOCELL can, therefore, also bring benefits in fabric softness.

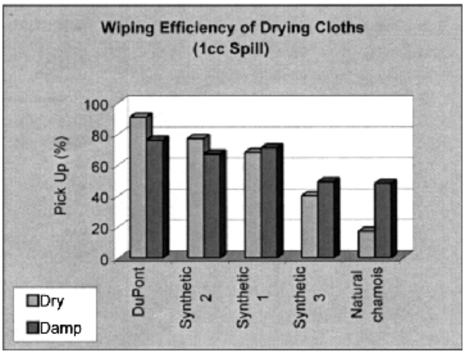
8-10mm ACORDIS LYOCELL can be used in cylinder-type air-lay processes. Here, the use of longer fibre lengths gives further improvements in properties.

Wipes

ACORDIS LYOCELL's unique combination of strength, absorbency and fibrillation potential make it an ideal component in products for a variety of wiping applications. Lyocell is already being used commercially in drying cloths, wipes for critical tasks (clean manufacturing environments, print and paint shops), food service wipes and patient washcloths in the medical industry.

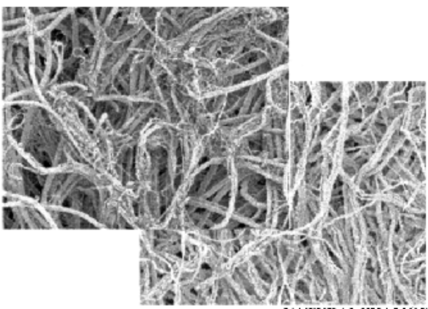
Drying Cloths

A commercial drying cloth based on ACORDIS LYOCELL shows faster rates of water absorption than competitive products. Owing to its high rate of demand absorbency and absorbent capacity, this wipe absorbs more surface water than competitive products in a test to simulate wiping.



The lyocell based drying cloth is as strong as natural chamois and can be washed repeatedly. Wiping performance actually improves with repeated washing.

ACORDIS LYOCELL



NATURALCHAMOIS

The fibrillated ACORDIS LYOCELL fibres are able to simulate the collagen microfibre structure of natural chamois better than typical man-made drying cloths.

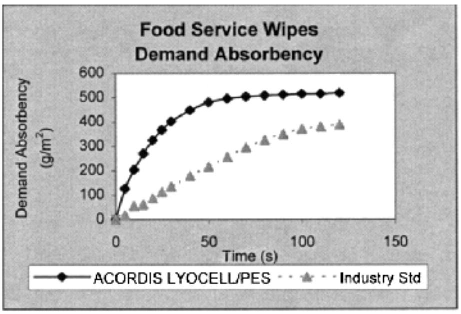
Furthermore, unlike natural chamois, the lyocell-faced cloth does not feel slimy when wet and stays soft even when dry.

Critical Task Wipes

These wipes are used in a variety of applications where low linting fabrics are required, such as clean manufacturing environments and automotive or boat painting and refinishing. The presence of ACORDIS LYOCELL enhances various critical performance features of hydroentangled critical task wipes. The product absorbs liquid faster and has a higher wet tensile strength, but stays soft, preventing the risk of abrasion damage. ACORDIS LYOCELL gives lower linting without the use of binders.

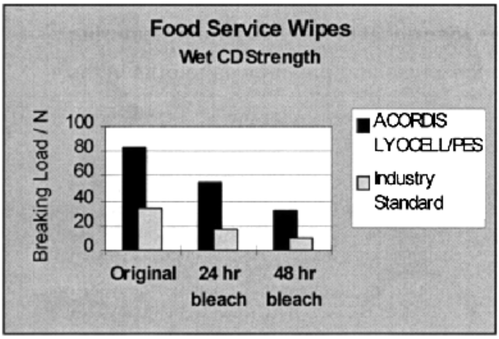
Food Service Wipes

Apertured spunlaced food service wipes made from a blend of ACORDIS LYOCELL and polyester offer several advantages over an industry standard 2 oz/yd^2 wipe. Demand absorbency is 7 times faster and capacity is 60% greater. There is also less residual smearing when wiping ketchup in a wiping simulation test.



The product has twice the CD wet strength and remains stronger after extended bleaching.

As well as being stronger and more absorbent it is also softer.



Baby wet wipes
ACORDIS LYOCELL also has the potential to create improved wet wipes, although these are not yet commercial. Lyocell enhances strength and stability, increases wet resiliency and gives improved crease definition. ACORDIS LYOCELL also gives excellent embossing clarity so is ideal for creating novel surface texture effects.

Medical Swabs and Gauzes

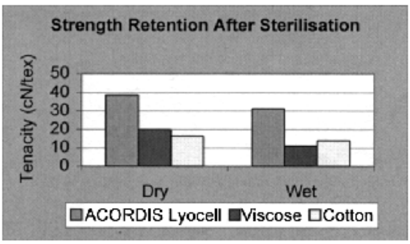
ACORDIS LYOCELL exhibits good hydroentanglement efficiency, delivers aperturing clarity, and provides strong, stable, low linting absorbent fabrics ideal for use in medical applications. Hydroentangled ACORDIS LYOCELL fabrics are significantly stronger than those produced from other cellulosic fibres. It meets the necessary standards required of fabrics for medical uses and provides an ideal partner for blends.

Hydroentangled fabrics continue to take an increased share of the swab and gauze market. The performance of ACORDIS LYOCELL is ideally suited to the hydroentanglement process. The fibre's high wet and dry strength can be translated into high fabric strengths.

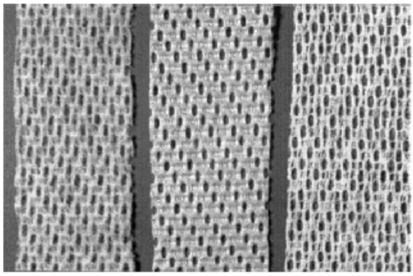
Plain and apertured hydroentangled fabrics can be produced using ACORDIS LYOCELL down to 20gsm. Strong stable fabrics can be made at a range of pressures without the use of binders. When bonded at low pressures, ACORDIS LYOCELL fabrics are exceptionally soft, have an attractive, silky appearance and particularly good drape characteristics. At higher bonding pressures a firmer handle is obtained which can assist debridement.

Hydroentangled ACORDIS LYOCELL has US FDA 510K approval covering its use in sensitive medical applications. 100% ACORDIS Lyocell products are completely biodegradable.

A cellulosic fibre needs to perform acceptably following sterilisation as a pre-requisite to finding widespread acceptance in nonwoven medical end-uses.

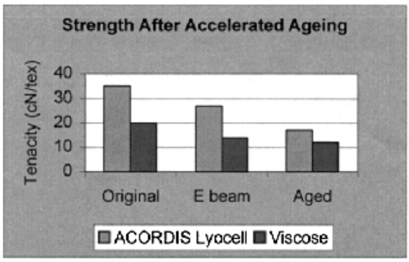


ACORDIS LYOCELL has been found to have excellent aperturing and embossing clarity compared to other cellulosic fibres used in hydroentanglement, making excellent fabrics for gauzes. ACORDIS LYOCELL is supplied in a delustred form to provide a non-reflective surface in use.



ACORDIS LYOCELL can be readily used in blends with viscose to improve both wet and dry strengths of hydroentangled nonwovens. Blends with polyester have also produced highly absorbent products.

ACORDIS LYOCELL has similar absorbency to viscose fibre, but this is significantly improved when blended with polyester, which is primarily due to the higher resilience of lyocell fibre.

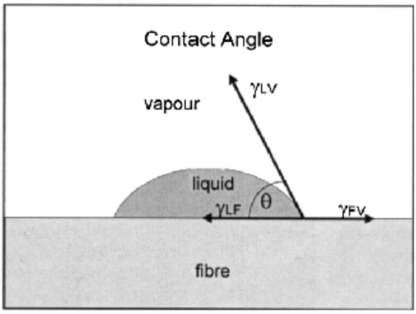


ACORDIS LYOCELL fibres are produced to meet the pharmacopoeia requirements originally devised for woven cotton products. Product development is designed to meet customers specific requirements.

Absorbency

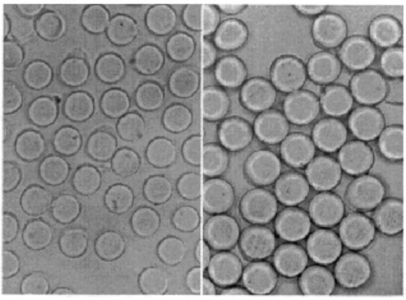
The affinity of ACORDIS LYOCELL for water lends itself to a range of applications in absorbent products. Like viscose rayon, ACORDIS LYOCELL has a highly wettable surface and inherent fibre absorbency. However, ACORDIS LYOCELL exhibits less wet collapse than rayon, thanks to its high wet modulus. This resiliency can boost absorbent capacity as well as maintaining pore integrity for faster wicking.

ACORDIS LYOCELL is hydrophilic and swells in water, making it suitable for a range of applications in absorbent products.



The fibre has a similar fibre/water contact angle to viscose rayon (10-40° depending on surface finish), leading to rapid fibre surface wetting on exposure to water.

After water penetration, the fibre cross sectional area increases by 50% - over twice the swelling of cotton.

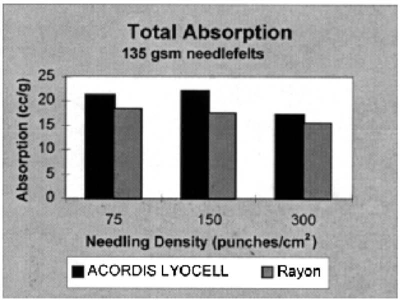


ACORDIS LYOCELL swelling in water

Such swelling enhances liquid transport within and between fibres, which can be particularly important in applications where liquid is moved vertically against the force of gravity.

ACORDIS LYOCELL has a higher water imbibition than cotton, but lower than viscose (ACORDIS LYOCELL 65%, cotton 45%, viscose 95%).

Generally, structures made from viscose lose bulk when wetted, due to the fibre's low wet modulus. This reduces inter fibre pore volume and so lowers the total absorbent capacity. The high wet modulus of ACORDIS LYOCELL makes it resistant to such wet collapse, offering the potential to improve absorbent capacity. For example, ACORDIS LYOCELL gives a higher total absorption than viscose in this series of needlefelts.



The rate of fluid absorption depends on pore size. Smaller dry pores increase the capillary force which drives fluid uptake, whilst larger wetted pores reduce the viscous drag that slows down fluid transport. The rates of transplanar absorption and wicking in a fabric are therefore highly dependent on fabric construction.

In viscose nonwovens, wet collapse can drastically reduce the size of pores in the wet structure, increasing the drag forces that inhibit flow. By contrast, the resiliency of ACORDIS LYOCELL helps to maintain pore integrity and favours faster wicking rates.

Chemical and UV Resistance

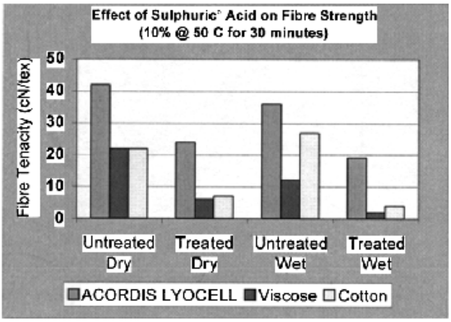
In addition to having a higher initial strength, ACORDIS LYOCELL outperforms other cellulosic fibres in its ability to retain fibre strength and integrity when exposed to mineral acids or UV irradiation.

Chemical Properties

ACORDIS LYOCELL degrades hydrolytically when in contact with hot dilute or concentrated mineral acids. The fibre swells when first exposed to alkalis (maximum at 9% NaOH solution at 25°C) and then ultimately, disintegrate.

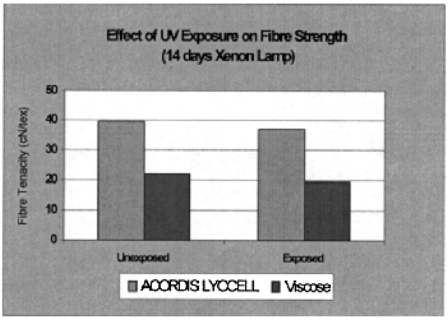
Strength Retention

Cellulosic fibres are not usually regarded as being resistant to degradation by acids or alkali. However, ACORDIS LYOCELL not only resists the degradative effects of mineral acids better than both cotton and viscose, but also retains a higher proportion of its already superior wet and dry strengths.



UV Resistance

ACORDIS LYOCELL retains its significant strength advantage over viscose following prolonged exposure to UV irradiation. After 14 days exposure to a Xenon lamp (equivalent to 140 days of direct sunlight) the fibre tenacity is reduced by less than 10%.



Swelling

Lyocell swells when in contact with either acids or alkali in a comparable way to viscose.

% Fibre Swelling	Sulphuric Acid Concentration		Sodium Hydroxide Concentration	
	0.1%	1.0%	1.0%	10.0%
ACORDIS LYOCELL	46	47	50	1345
Viscose	69	49	101	1059

Biodegradation

Cellulose is the natural polymer that makes up the living cells of all vegetation. It is the most abundant and renewable biopolymer on Earth. Like all cellulosic fibres, products made from ACORDIS LYOCELL are completely biodegradable and can be composted, digested in sewage, landfilled or incinerated.

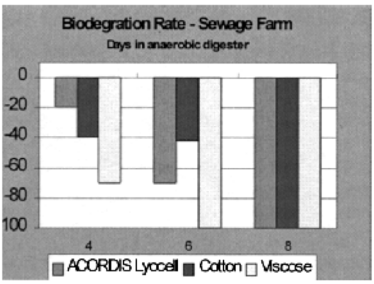
Biodegradation occurs through the action of enzymes created by living organisms, breaking a product down to carbon dioxide (CO_2) and water (H_2O). Cellulosic fibres commonly used in nonwoven products such as ACORDIS LYOCELL, viscose and cotton are known to be biodegradable, whereas synthetic fibres are not.

Composting

ACORDIS LYOCELL and viscose fibres were found to have degraded completely after 6 weeks in a static aerated compost pile, and cotton fibre had suffered a weight loss of 80%. The synthetic fibres tested, polyester, polypropylene and polyethylene, showed very little signs of degradation.

Sewage Treatment

Sewage treatment plants and septic tanks operate mainly under anaerobic conditions, though some parts of the process are aerobic. The microorganisms present in sewage are accustomed to breaking down cellulosic products such as tissue paper. The resultant natural gas generated can be used to power the sewage treatment works.



ACORDIS LYOCELL, viscose and cotton fibres degrade completely within 8 days in a typical sewage farm anaerobic digester, where the residence cycle is about 20 days. The synthetic fibres tested show slight reductions in tensile strength after 12 weeks in an anaerobic digester. Similar results would be obtained in septic tanks.

Landfill

Organic matter buried in the ground rots over a period of time by the bacterial process of anaerobic digestion. A landfill site is not easy to define or simulate, as it is somewhat heterogeneous. Soil burial tests (BS 6085 /AATCC 30) are accepted methods of assessing the biodegradability of a product. ACORDIS LYOCELL, viscose and cotton fibres degrade completely within 12 weeks. Synthetic fibres gain weight initially, and only show slight strength and weight loss after 24 weeks burial.

The result of the biodegradation studies carried out to date correlate well with the knowledge we have regarding the structure and chemical resistance of cellulosic and synthetic fibres.

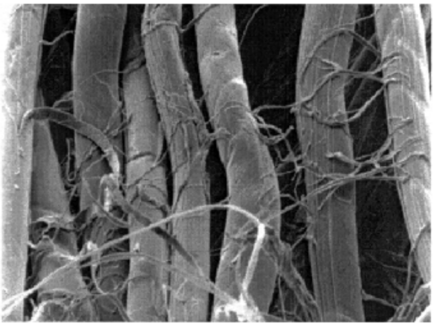
Incineration

Mass incineration plants especially in large conurbations, with facilities for recovering energy from waste, can earn substantial amounts of money from the sale of electricity to power generating companies. Cellulosic fibres, such as ACORDIS LYOCELL burn readily with a heat of combustion of 15 kJ/g. Such plants also have the added advantage of reducing the volume of refuse sent to landfill sites by as much as 90%.

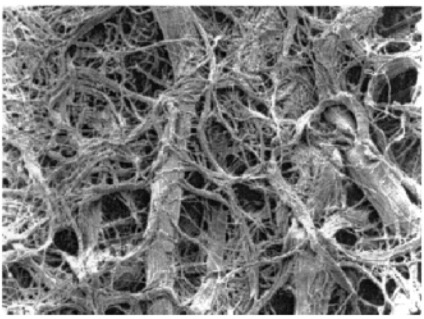
100% ACORDIS LYOCELL Papers

The ability of ACORDIS LYOCELL fibre to split into micro-fibres during wet processing makes it ideal for use in papers. The long fibre length and round sub-micron fibrils can improve paper properties such as tear strength, opacity and air permeability. These properties can be tailored by controlling the amount of fibrillation generated on the fibre.

ACORDIS LYOCELL Low fibrillation

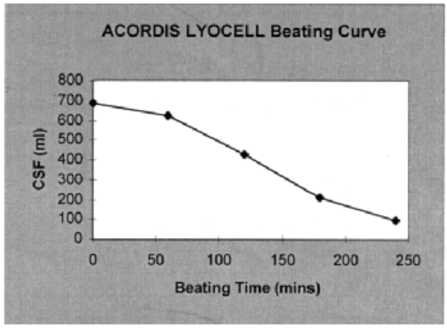


ACORDIS LYOCELL Highly fibrillated

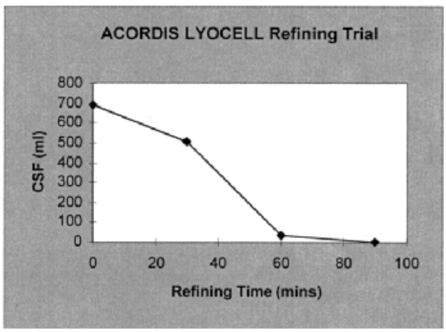


The potential for ACORDIS LYOCELL fibre to fibrillate into micro-fine fibrils makes it ideal for use in special papers. This fibrillation can be achieved using papermaking equipment such as beaters or refiners or by vigorous mixing in a hydrapulper or high shear mixer.

Laboratory beating demonstrates the potential for lyocell fibre to be fibrillated to a range of levels, as indicated by the Canadian Standard Freeness test for drainage rate.



Pilot scale refining work has demonstrated the potential for fibre fibrillation, whilst plant scale trials have confirmed that lyocell can be processed using standard papermaking equipment. ACORDIS LYOCELL has been successfully fibrillated in beaters, refiners and hydrapulpers



The unique nature of ACORDIS LYOCELL and of the fibrillation generated from it, results in characteristic paper properties: papers with good tensile strength, outstanding tear strength and high opacity can be made.

Lyocell papers also have relatively high air permeability compared to woodpulp papers due to the circular cross-section of the fibres and fibrils.

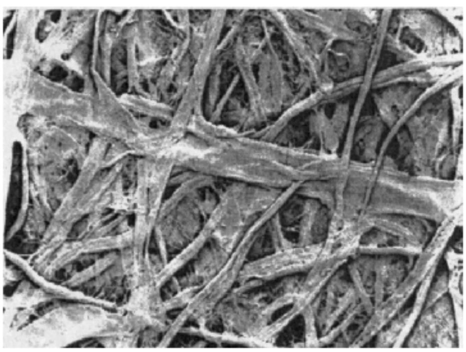
Typical water leaf paper results show how the generation of fibrillation influences sheet performance and the interesting combination of properties which are generated. As more fibrillation is produced, tensile and tear properties increase. Air resistance increases although it remains low compared to a paper produced from woodpulp. Opacity of the paper increases as refining progresses.

Recommendations for wet strength resins suitable for use with ACORDIS LYOCELL can be supplied. Laboratory work has shown that wet and dry properties can be improved without adversely affecting air permeability.

ACORDIS LYOCELL is suitable for a wide range of special paper types covering end-uses such as filters, battery separators, food casings, map and chart papers, tea bags, cigarette papers, bank-note and security papers.

ACORDIS LYOCELL papers have gained German BGA approval for use in food contact applications.

100% Lyocell, refined at 0.75% consistency, SEL 0.2 Ws/m	Refining Energy (kWh/tonne)			
	0	200	400	600
Freeness (ml)	800	607	93	0
Basis Weight (gsm)	79.3	68.5	66.8	66.4
Thickness (microns)	256	178	151	135
Bulk (cc/g)	3.2	32.6	2.3	2.0
Tear Strength (mN)	584	2237	1823	973
Burst Strength (kPa)	18.8	101	120	136
Tensile Strength (N/15mm)	3.8	15.8	25.3	30.7
Breaking Length (km)	0.3	1.8	2.57	3.2
Stretch (%)	1.9	1.7	2.6	2.2
Double Folds	0	15	69	287



Woodpulp Fibrillation

ACORDIS LYOCELL Fibrillation

Blends

ACORDIS LYOCELL is ideal for use in blend with woodpulp and can enhance specific properties, such as tear, opacity and filler retention. The fibre can also be used as a binder for microglass fibres.

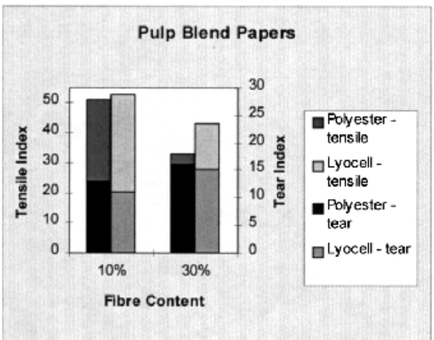
ACORDIS LYOCELL can be used to enhance specific properties of papers when combined with other fibres and it is particularly effective in improving tear strength and opacity as well as in reducing air resistance.

ACORDIS LYOCELL can be used readily in blend with a wide range of other fibres. For example, in laboratory work, addition of lyocell to a typical pulp stock (70% hardwood, 30% softwood) gave improvements in a range of properties.

	Tear Index ($mN.m^2/g$)	Tensile Index (Nm/g)	Burst Index ($kPa. m^2/g$)	Air Resistance (secs)	Opacity (%)
100% Pulp	11.0	52.5	4.7	10.4	71.3
90% Pulp 10% unbeaten ACORDIS LYOCELL	13.2	50.4	4.35	4.01	73.2
90% Pulp 10% 230 CSF ACORDIS LYOCELL	13.8	60.4	4.0	9.8	74.8

The improvement in properties which can be obtained by inclusion of ACORDIS LYOCELL makes it a highly suitable alternative to other reinforcing fibres.

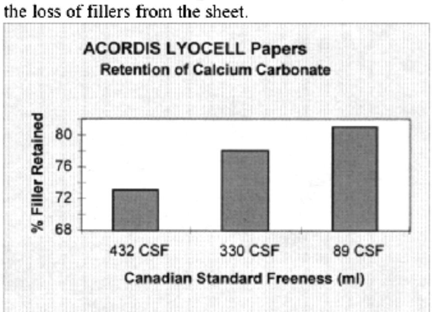
For example, short cut polyester is commonly used for tear strength enhancement.



Results show lyocell to give very similar improvements in tear than polyester, when blended with pulp. Tensile results are also similar. Additionally, using lyocell has the advantage of maintaining a furnish composed of 100% cellulose.

ACORDIS LYOCELL can also be used in blend with synthetic fibres, which do not self-bond readily and normally require a chemical bonding agent. Papers can be made from blends of lyocell with microglass without the need for an additional binder - the lyocell adds strength and flexibility to the sheet. Alternatively, inclusion of ACORDIS LYOCELL could allow a reduction in the amount of binder required for a paper.

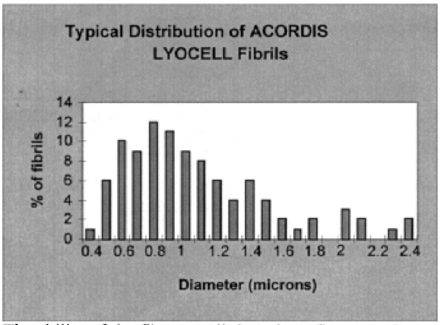
ACORDIS LYOCELL can also be used as an agent to aid retention of fillers in papers - the fine fibrils allowing particulates to be held in place effectively. This can enable the inclusion of higher levels of filler, or reduce the loss of fillers from the sheet.



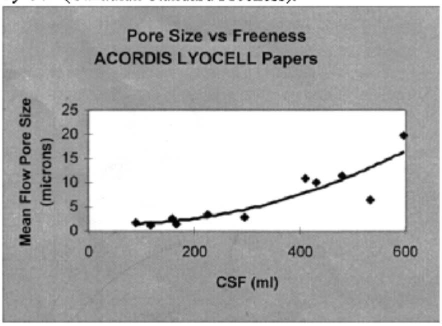
Filtration

The ability for ACORDIS LYOCELL fibre to split into circular, sub-micron fibrils generates the potential to capture small particles, whilst maintaining good air permeability. These properties make ACORDIS LYOCELL an ideal fibre for filtration applications.

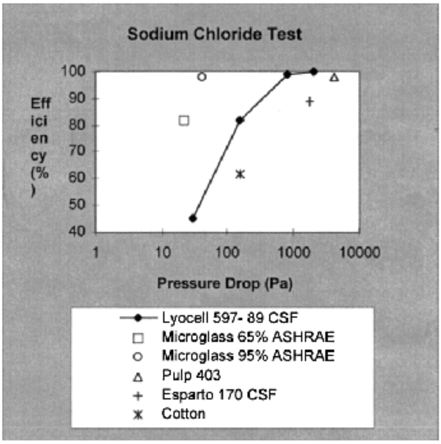
One of the many end-uses for which ACORDIS LYOCELL is ideally suited is in the area of filtration. Lyocell fibre can be processed into a fibrillated paper using standard papermaking techniques. The papers produced are strong and have unique properties as the fibrils produced from the fibre are mainly circular in cross-section, with a range of diameters down to sub-micron levels.



The ability of the fibre to split into these fine, round fibrils means that papers can be made which are ideal for filters - having good permeability coupled with the ability to capture small particles effectively. The pore size of the papers and hence their efficiency can be controlled readily by altering the level of fibrillation generated. This is demonstrated by comparing pore size (measured using a Coulter Porometer) with fibrillation level as measured by CSF (Canadian Standard Freeness).



The filtration efficiency of papers made from ACORDIS LYOCELL can be demonstrated using a standard air filtration test. Using a sodium chloride aerosol challenge (BS4400) to assess the performance of flat papers, fibrillated ACORDIS LYOCELL papers were compared with commercial samples of microglass and cellulose (woodpulp) filter papers.

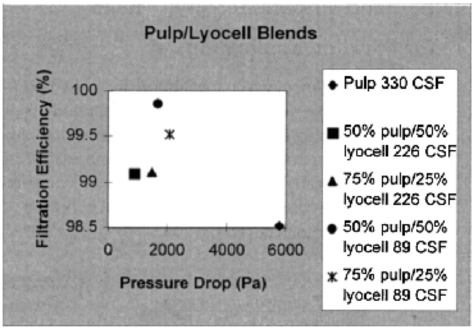


The results demonstrate the performance advantage of ACORDIS LYOCELL papers over woodpulp sheets - higher efficiency at a lower or comparable pressure drop.

Compared to microglass, ACORDIS LYOCELL papers do show higher pressure drops, though the paper properties are significantly better and have the additional advantage of requiring no binder.

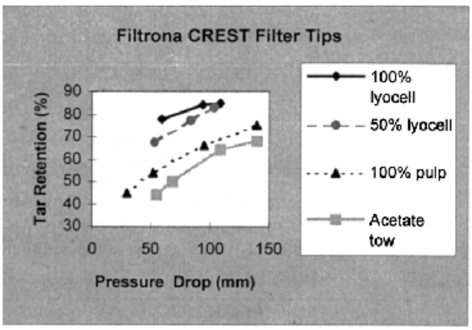
	Tensile Index (Nm/g)	Tear Index (mN.m²/g)	Bulk (cc/g)
Microglass	5.1	5.5	7.7
Woodpulp	14.8	4.7	2.2
ACORDIS LYOCELL	10.7	16.0	4.0

Although ACORDIS LYOCELL can be used alone, it is particularly suited to being used in blends. Significant advantages can be achieved using lyocell in combination with other fibres to engineer a product with the correct filtration characteristics. Fibre fibrillation levels can be tailored to suit the application and complement the other fibres being used. Work in blending pulp and lyocell has shown that addition of ACORDIS LYOCELL can improve filtration efficiency without impairing pressure drop.



In combination with glass fibre, lyocell offers the opportunity to improve paper strength and integrity, without severely affecting filtration performance. The requirement for binders can also be reduced.

One product which utilises the characteristics of lyocell paper is the CREST™ cigarette filter, developed by ACORDIS in collaboration with Filtrona International Ltd. The Crest material was developed for use in ultra-low tar products (1-2 mg tar) which require a combination of very high tar retentions with acceptable resistance to draw (i.e. pressure drop).



The optimised ACORDIS LYOCELL paper has a intermediate level of fibrillation giving a retentive yet permeable sheet. A blend of pulp and lyocell can also be used. The paper is made into a filter tip in the same way as a normal pulp paper. However, filtration results show the superior performance of both 100% ACORDIS LYOCELL or 50% lyocell 50% pulp, clearly differentiated from acetate or semi-crepe paper tips.

The exceptional performance of ACORDIS LYOCELL paper in filter tips is due to its unique filtration characteristics. The Filtrona CREST™ filter offers design opportunities in the growing ultra-low tar cigarette market, and clearly demonstrates the potential offered by ACORDIS LYOCELL in filtration applications.

Fibrillation of ACORDIS LYOCELL can also be accomplished in structures other than papers for example during hydroentanglement or any wet processes. Such fibrillated fabrics and structures exhibit similar advantages in filtration applications.

Examples of specific filtration applications for ACORDIS LYOCELL include automotive filters (fuel, oil, air), HEPA and ULPA filters, medical filters, vacuum bags and food and beverage filters.

ACORDIS LYOCELL papers have obtained German BGA approval for use in food contact applications.

Appendix B

Archive photographs of regenerated cellulosic fibre processes

The photographs in this appendix are presented courtesy of the Akzo-Nobel (UK) Ltd Archives in Coventry.

Plates 1 to 8 illustrate progressive developments in yarn handling methods from the 1930s' cake-spinning/hank-winding process (Plate 1, but see also Fig. 1.3 in Chapter 1 for the 1905 cake spinning machine) through continuous-warp spinning/washing of tyre yarn (Plates 2 and 3, but see also Fig. 9.5 in Chapter 9 for the self-advancing reel spinning system) to the staple fibre spinning/washing system (Plates 4 to 8).

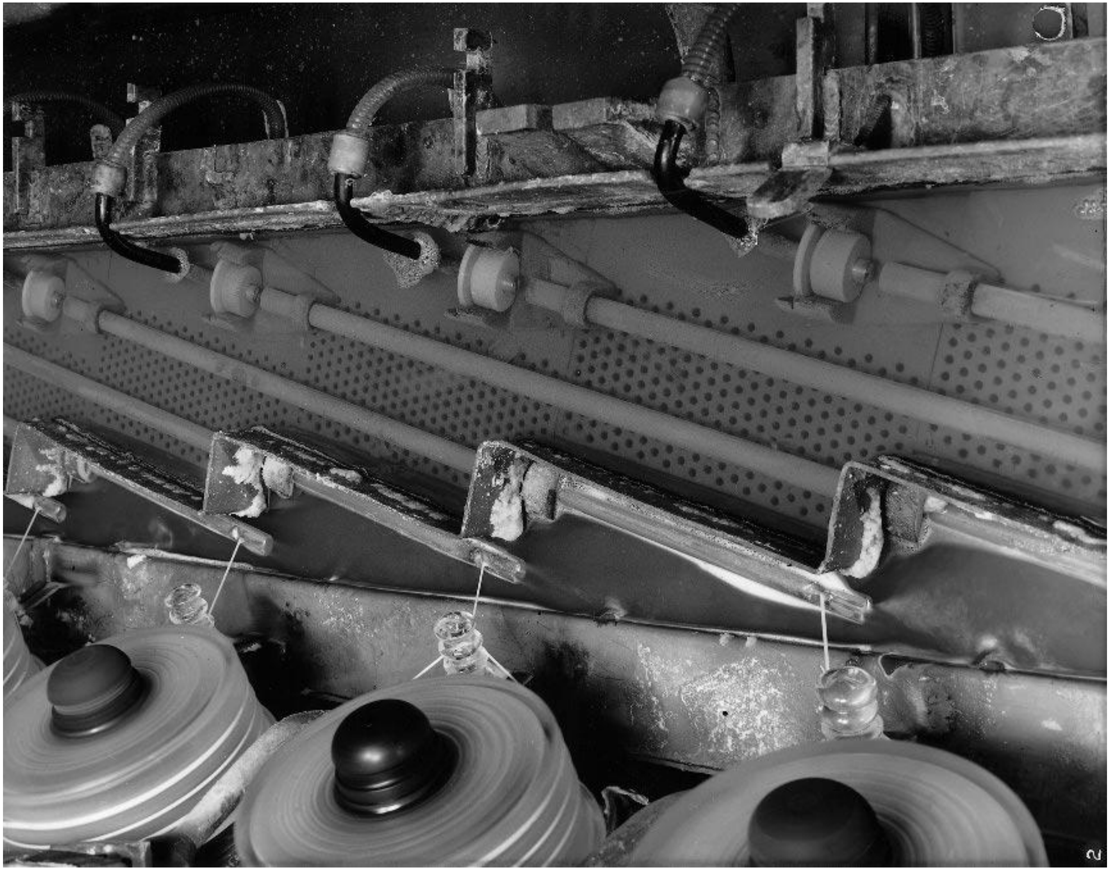
Plates 9 and 10 are diacetate spinning, a dry process requiring no washing equipment.

Plate 11 shows the mixing of the extremely viscous hot lyocell dope in an early pilotscale mixer.

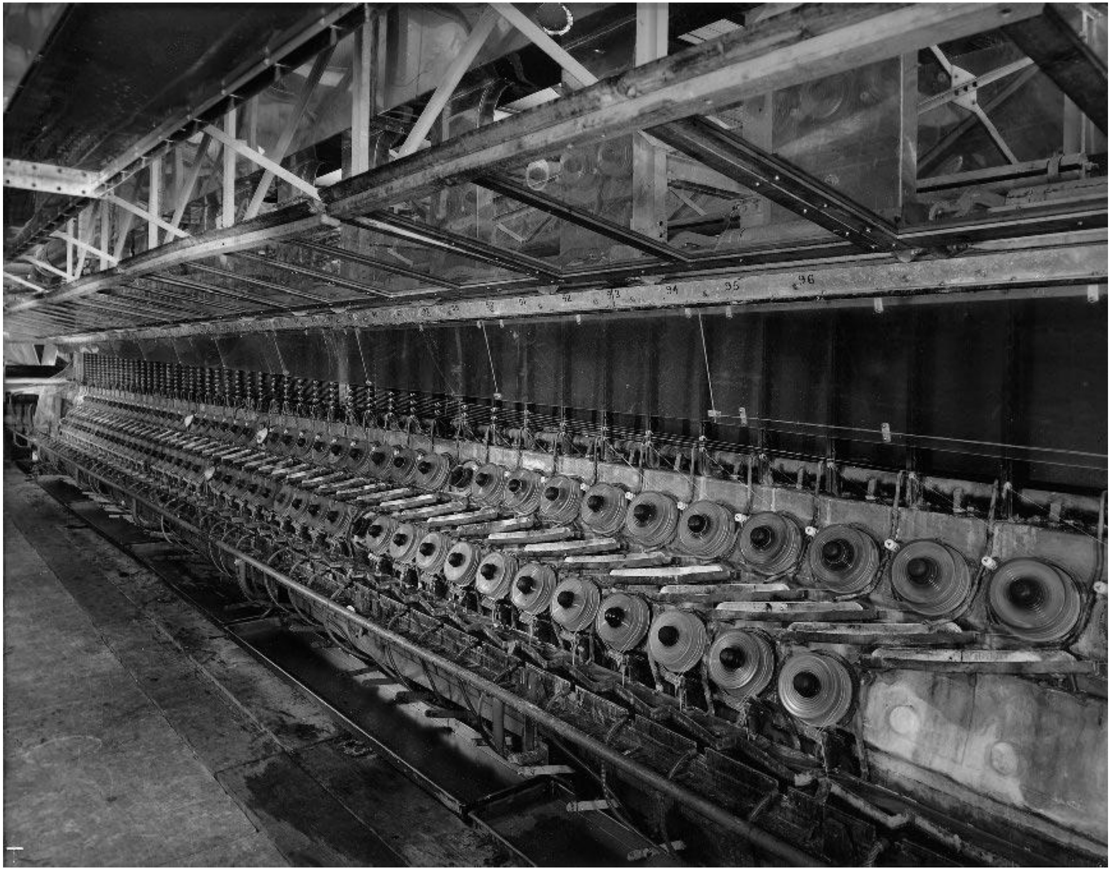
Plate 12 shows the ease with which the hot lyocell dope can be dry-formed into fibres.

Plate 13 shows extrudable glass-like 'chips' of solid cellulose-in-NMMO.

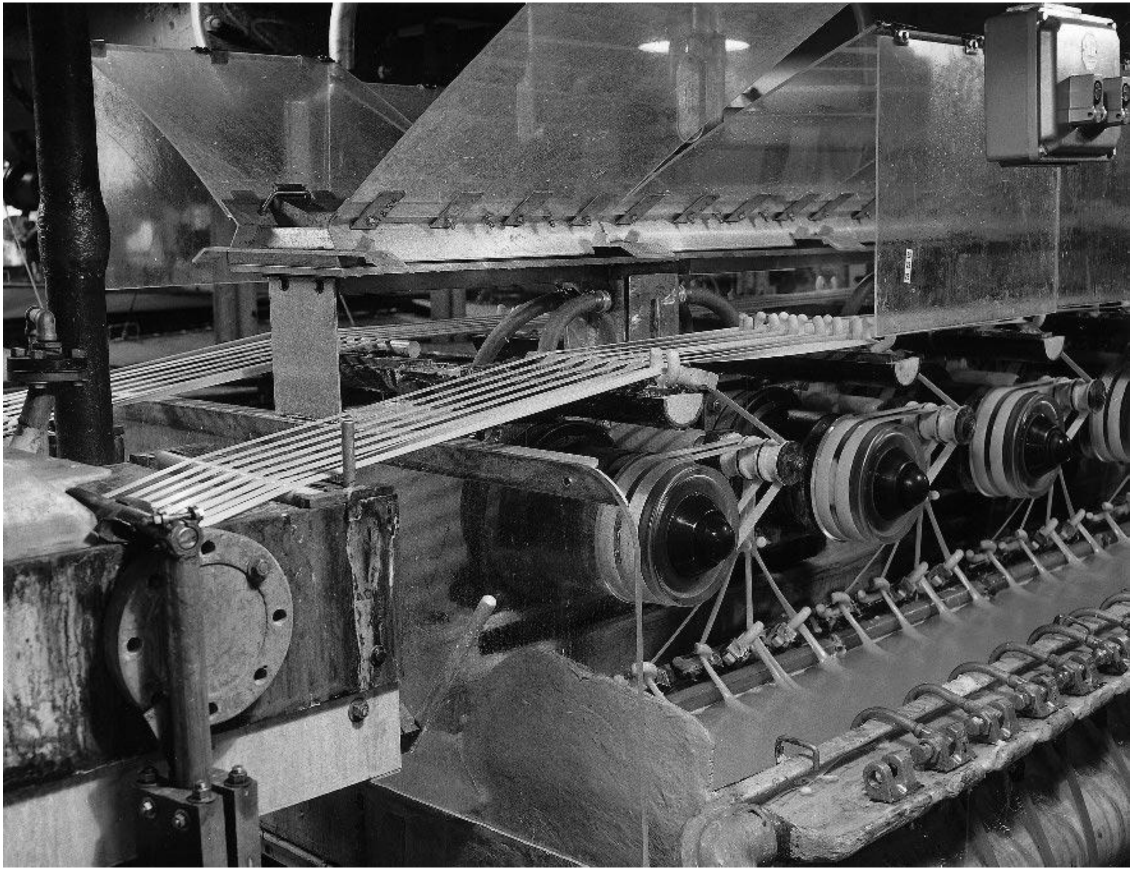
1 Viscose filament yarn process circa 1930: preparing hanks for washing.



2 Viscose tyre yarn process: tube spinning.

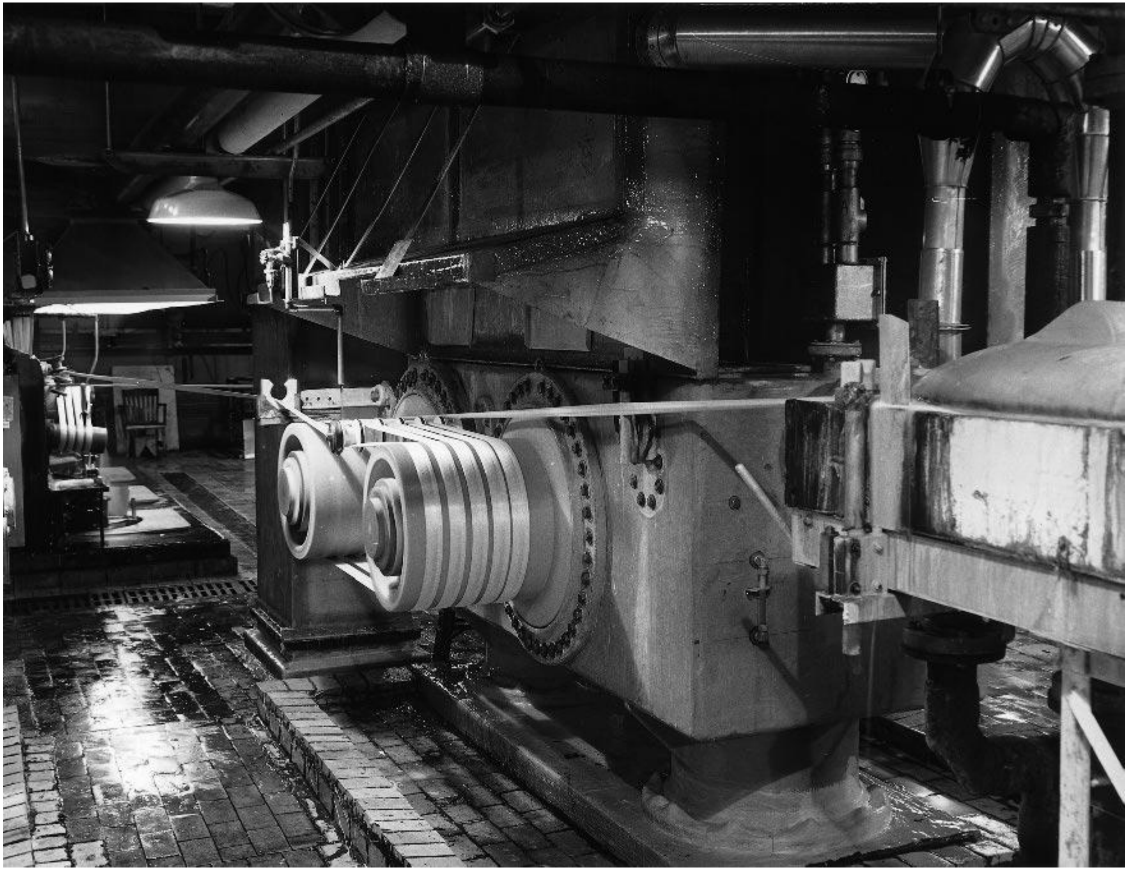


3 Viscose tyre yarn spinning: warp process.

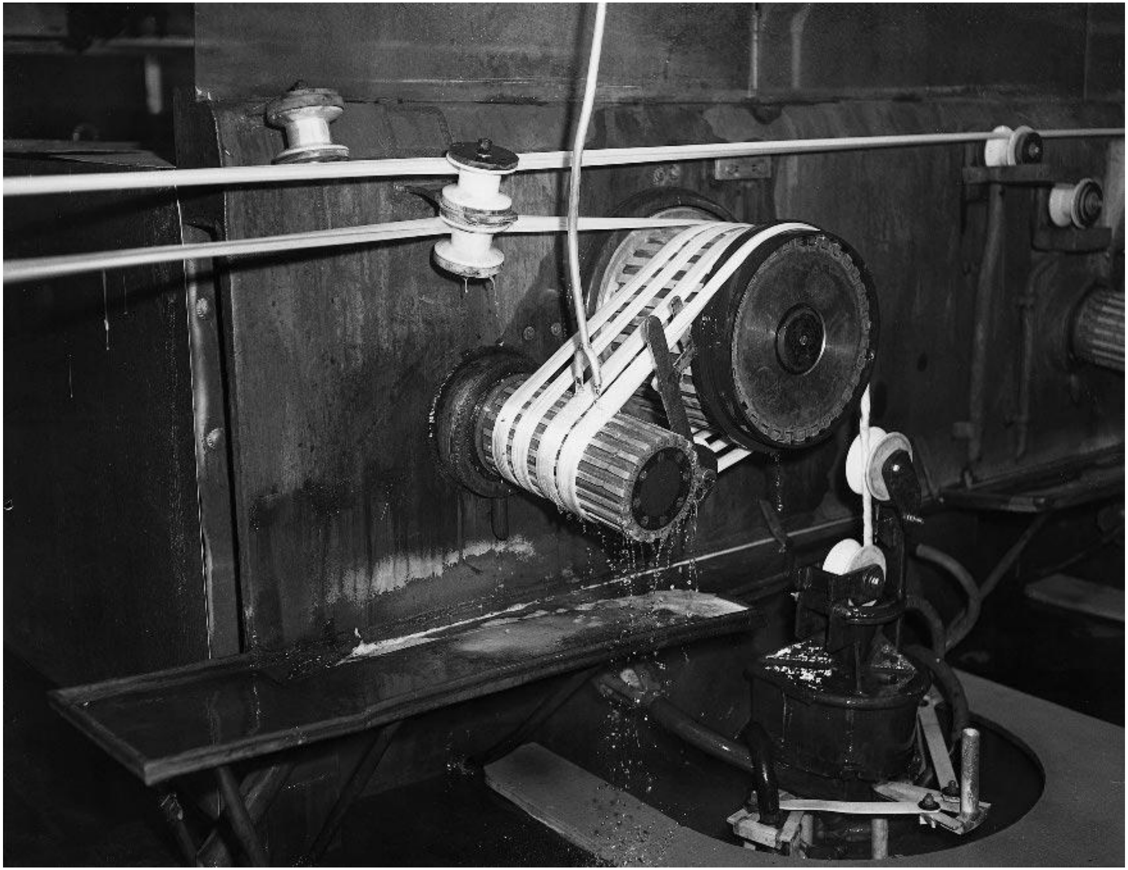


4 Viscose staple fibre process: spinning.

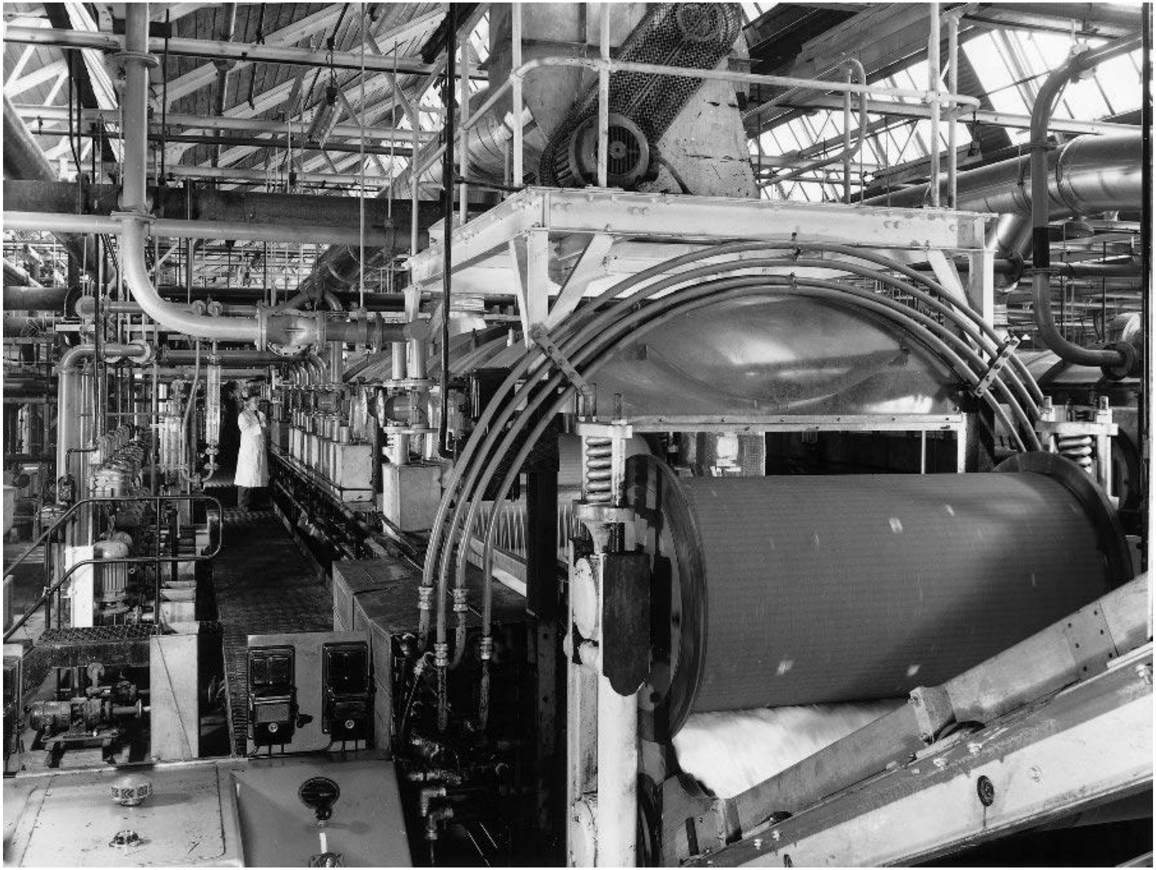
5 Viscose staple fibre process: hot stretching the tows.



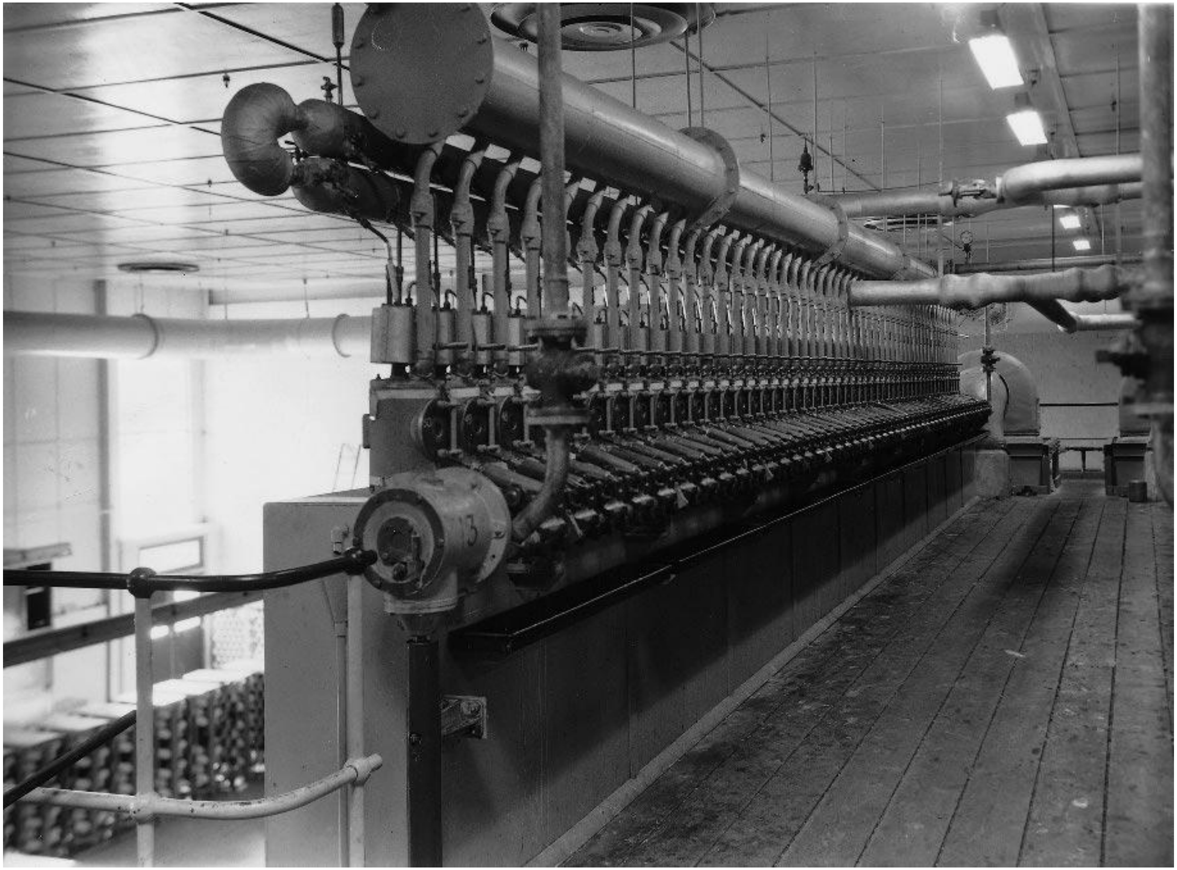
6 Viscose staple fibre process: traction unit after hot stretching.



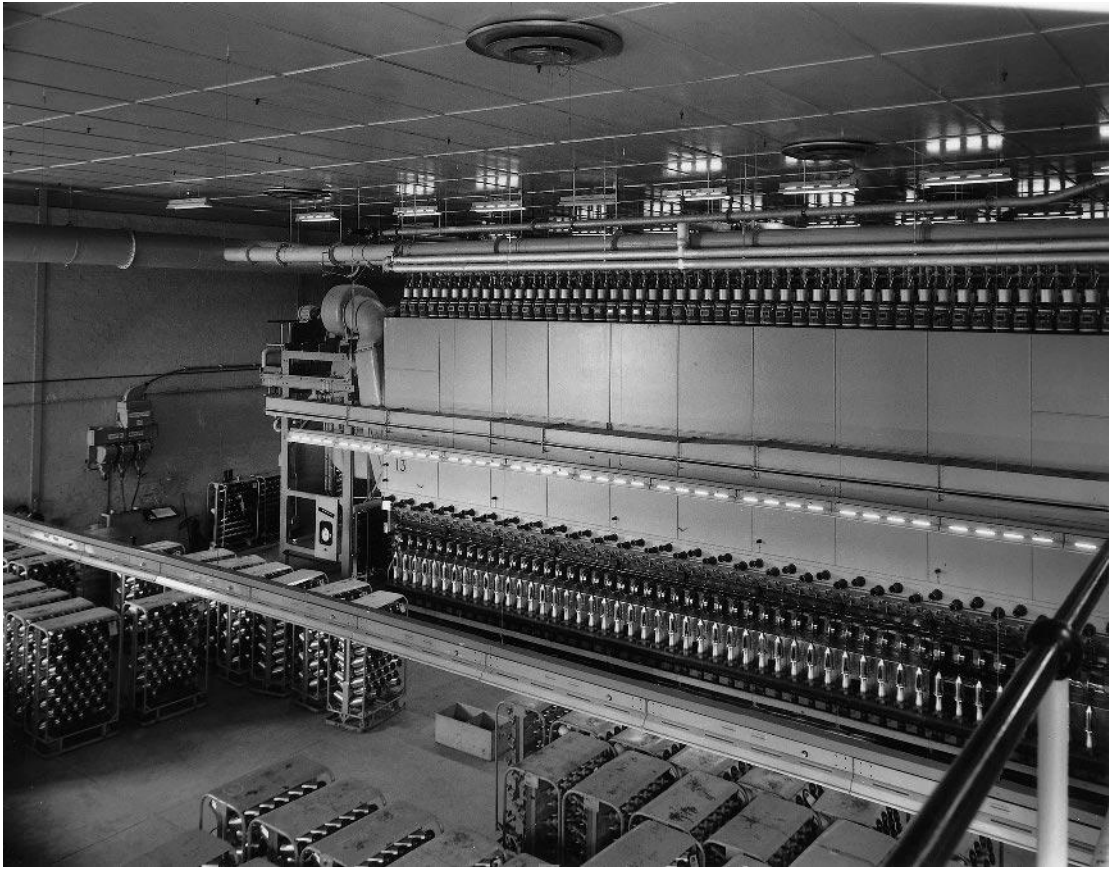
7 Viscose staple fibre process: feeding the tow cutter.



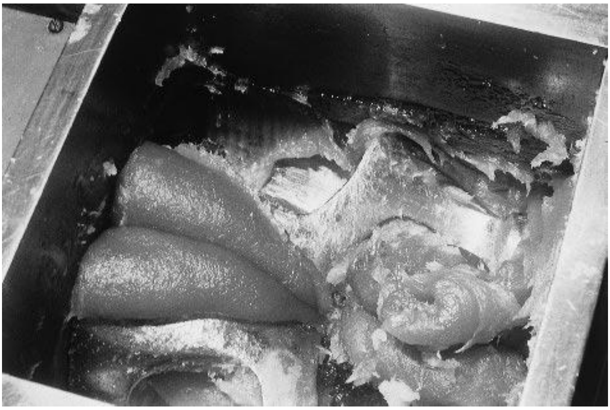
8 Viscose staple fibre process: wash machine.



9 Dry-spinning: diacetate yarn machine spindeck.

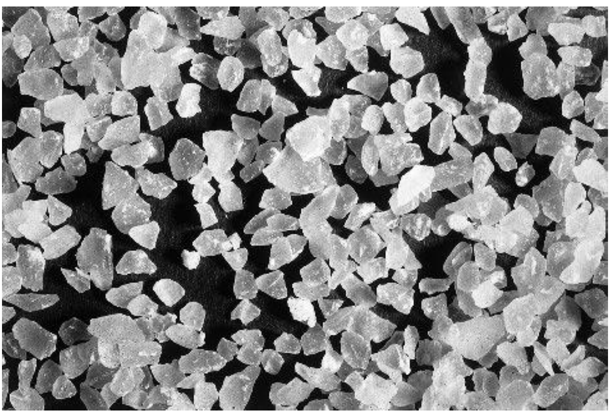


10 Diacetate yarn spinning machine.



11 Cellulose in NMMO: premix.

12 Cellulose in NMMO: fibre-forming potential evident.



13 Cellulose in NMMO: chips of solid cellulose.

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