Nonwoven Fabrics

Edited by
Wilhelm Albrecht
Hilmar Fuchs
Walter Kittelmann

WILEY-VCH

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Foreword

When in 1981 the world's first authentic and complete handbook on Nonwovens was published, the authors Albrecht and Lünenschloß already noted that these initially relatively simple substitution products had become an independent and technically sophisticated industry in its own right. Nonwovens owed their growth to an unusual multiplicity of raw materials and process options.

Since than 20 years have passed. Sales, distribution and diversity of an originally young and modest industry, whose focal points were clearly in Europe and USA, have multiplied. Experts expect a worldwide production of approx. 3.3 mio. tons at a market value of approx. US$ 14.6 billion in the year 2000. This means more than 5% of conventional textile production will already be represented by Nonwovens. In numerous market segments, Nonwovens already play a leading role. In certain areas they have assumed genuinely novel functions – for example in textiles for personal and medical care.

Without doubt, the Nonwovens industry has also suffered during the course of its 50-years maturing process. Several markets are not longer growing or do not allow economically acceptable returns on investment any more. In a number of regions and market segments undiscriminating investments and the availability of turn-key technology have done severe harm to the industry.

For the qualified and responsible producer, however, the Nonwovens industry continues to offer endless new challenges and opportunities. Not many other fields of endeavour offer such creative diversity of raw materials and processes as well as a limitless variety of finishing and application possibilities in order to fulfil customer demands with tailor-made solutions. In this respect innovative Nonwovens producers can have confidence in a successful future.

In this spirit I welcome the new up-dated and extended version of the Nonwovens handbook and wish both, the authors and the publishers, the success they deserve. We all shall stand to benefit.

H.N. Dahlström

Preface

Twenty years ago, the reference book “Nonwovens” was kindly received by all concerned with textile manufacturing. In that book, more than 20 authors described in detail the raw materials, their processing into a wide range of nonwoven products, the characteristics of the products and the testing techniques then in use. “Nonwovens” was much asked for in industry, education and, with regard to new products, in R&D. Meanwhile, the quantity of nonwovens made worldwide has grown, the range of goods based on nonwovens is much wider, the technical equipment, the raw materials as well as the auxiliaries used have been further developed. Therefore, the idea did not come as a surprise to revise the book. This meant to find a team of authors fully conversant with the current state and the quantitative and qualitative developments going on in a field of industry which is – as hardly any other industry – run on a worldwide scale. A sophisticated project like this called for specialist co-ordination, which was provided by Sächsisches Textilforschungsinstitut in Chemnitz, a research institute preferably dealing with questions of nonwoven production and innovation in the field of nonwovens. This institute works closely together with companies that make or process nonwovens as well as with the suppliers of fibres, the manufacturers of the relevant equipment and the producers of auxiliaries, which has been very helpful.

Today, the nonwoven-producing industry is best characterized as an industry that has accomplished a rise in product quality which the user can see and feel. Its range of products has become ever larger. This has been achieved by creative work and successful co-operation with the suppliers of raw and auxiliary materials as well as the manufacturers of equipment. Based on this co-operation, there are good prospects for novel products coming. Future developments will, in the widest sense of the word, continue to focus on best-possible functionality and lowest-possible consumption of resources. To this end, it will be important all concerned work together even more closely. The editing team give their views of ways to go and aims to reach in the future in the last Chapter of this book headlined “outlook”, thus outlining the potential which is still waiting to be exploited. This book is supposed to contribute to developing the nonwoven-producing industry.

We have been lucky one of the editing team has been in a position to do all the work in detail required to prepare this reference book. This meant spending much time talking to the authors of the single Chapters and co-ordinating them.

More help was provided by Wiley VCH Publishers, who will, except for the German edition, publish the book in English and Chinese, too. We are grateful to Dr. Böck for comprehensive advice. Thanks to her efforts, the book includes advertisement which will help the nonwoven-producing industry to deliver best quality and to develop new products. Our thanks go to all authors and those who have contributed in whatever way.

Today, nonwovens are part of what is known as the world of textiles. Due to their tailor-made characteristics, they are highly suitable to meet a wide diversity of requirements. Thus, nonwovens are more than products which are up-to-date. They give evidence that it is possible to master the challenge of the future.

We hope the reader can make good use of this book.

Wilhelm Albrecht
Hilmar Fuchs
Walter Kittelmann

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Introduction to nonwovens

G. Massenaux

Whilst the first production of a “nonwoven fabric” in Europe goes back to the thirties, the existence of a recognizable nonwovens industry in Europe can be dated to the mid-sixties.

This is also when the terms nonwovens or *Vliesstoffe* got used, preferably to others, in a small circle of manufacturers and converters.

Since then, the manufacture of nonwovens has expanded rapidly and the use of such products has penetrated many aspects of industry and of private life. Nonwovens are found in hygiene and health care, in rooting and civil engineering, household and automotive, in cleaning, filtration, clothing, food wrap and packaging, to name only a few end-uses. Confusion or ignorance about nonwovens remains large though. The present book comes out therefore at the right time to give a comprehensive view of what is to be understood by nonwovens, their manufacturing process, applications and possibilities. Presenting in a coherent way the present state of the art of nonwovens manufacturing and end-uses will be an invaluable help to all those within the industry or outside of it who deal with nonwovens or might get the opportunity to do so.

It is to be hoped that this book will also have a seminal influence in attracting young talents to this growing industry, where so much still is needed in order to further develop machinery, raw materials and properties of nonwovens to their best use.

0.1

Definition of nonwovens

The term used to designate the products generally known as nonwovens, was coined in most languages in opposition to woven fabrics, which implicitly were taken as a reference. A nonwoven was something that was not woven.

Even the German name *“Vliesstoffe”* wasn’t clear either as it could be confused with ceramical material and in any case remained ambiguous in its unusual spelling. Only specialists know that nonwovens are unique engineered fabrics which offer cost effective solutions as e.g. in hygiene convenience items, or as battery separators, or filters, or geotextiles, etc.

There is a formal definition of Nonwoven: ISO 9092 [1] which bas been adopted by CEN (EN 29092) and consequently by DIN or AFNOR or any standardization office in the EU. Various legal or regulatory implications derive from it [2].

As a main characteristic the CEN definition indicates that a nonwoven is a fabric made of fibres, that is consolidated in different ways. Nonwoven fabrics are made out of fibres, without any restriction, but not necessarily from fibres. These can be very short fibres of a few millimetres length as in the wetlaid process; these can be "ordinary" fibres, as used in the traditional textile industry, or then very long filaments etc. Properties and characteristics of a nonwoven fabric depend for a large part from the type of fibre it is ultimately made of. These fibres can be natural or man-made, organic or inorganic; the characteristic of a fibre being that it is longer than its thickness, or diameter. Such fibres can also be produced continuously in connection with the nonwoven process itself and then cut to length, or then extruded directly e.g. from polymer granules into a filament and then fibrous structure.

To make good measure the ISO definition also excludes various types of fabrics to which, voluntarily or not, one might compare nonwovens. Nonwovens are not paper and indeed, when made out of very short, cellulose fibres, they essentially differ from paper because there aren't any, or hardly, hydrogen bonds linking such fibres together [3].

Nonwovens, as indicated by their English or French name, are neither woven fabrics, nor such other textiles as knitted fabrics. Behind these statements lies a fundamental characteristic of nonwoven: contrary to woven or knitted fabrics, fibres that ultimately make up the nonwoven fabric need not to go through the preparatory/transitory stage of yarn spinning in order to be transformed into a web of a certain pattern.

Some will remark that other textile fabrics were created in the past besides the weaving and knitting process, e.g. felting (which is also yarnless) or more recently stitchbonding. For this reason as well – especially in the early days – some have tended to literally classify as nonwovens all textile fabrics that are outside the weaving/knitting domain. Matters have settled since then and the reflexions at

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[1] A manufactured sheet, web or batt of directionally or randomly orientated fibres, bonded by friction, and/or cohesion and/or adhesion, excluding paper and products which are woven, knitted, tufted, stitch-bonded incorporating binding yarns or filaments, or felted by wet-milling, whether or not additionally needled. The fibres may be of natural or man-made origin. They may be staple or continuous filaments or be formed *in situ*. (This definition is completed by various notes.)

[2] The CEN nonwovens definition is adopted by EDANA, the European nonwovens industry association. INDA, the North American Association has a slightly different, wider definition which has the merit of apparent simplicity: a sheet, web or batt of natural and or man-made fibres or filaments excluding paper, that have not been converted into yarns and that are bonded together by any of several means (such means are then listed).

[3] There remain marginal cases with respect to paper or other fabrics which the ISO/CEN definition tries to deal with in its notes but we won't bother the reader with it. Like in nature there are some areas which can be contested between sea and terra firma and where the final accepted limit is somewhat arbitrary; or like in the plant/animal realm where the final distinction depends from the criteria that are finally adopted…

ISO and CEN helped clarify this. As far as textiles go, nonwovens are only part of a category of fabrics that exist besides weaving and knitting.

Nonwovens though go also beyond the limits of textiles. Fibres they ultimately are made of can be very short "unspinnable" ones like in the paper industry; the fibrous web can also originate from foils and other plastics. Nonwovens therefore share for a part manufacturing characteristics and properties with the paper industry or the chemicals/plastics industry to finally make a world of their own.

Nonwovens do not depend on the interlacing of yarn for internal cohesion. Intrinsically they have neither an organized geometrical structure. They are essentially the result of the relationship between one single fibre and another. This provides nonwoven fabrics with characteristics of their own, with new or better properties (absorption, filtration) and therefore opens them up to other applications.

0.2
Nonwoven manufacturing processes

There are three main routes to web forming:

- the drylaid system with carding or airlaying as a way to form the web;
- the wetlaid system;
- the polymer-based system, which includes spunlaying (spunbonding) or specialized technologies like meltblown, or flashspun fabrics etc.

The lack of sufficient frictional forces however bas to be compensated for by the bonding of the fibres, which provides web strength. Consolidation of the web after its formation is the second step in the nonwoven manufacturing process.

This consolidation for a large part sets the final characteristics of the fabric and therefore, if possible, ought to be chosen with the end application in mind. Such consolidation can be done by use of chemical means (chemical bonding) like binders. These can be applied uniformly by impregnating, coating or spraying or intermittently, as in print bonding. The consolidation can also be reached by thermal means (cohesion bonding), like the partial fusion of the constituting fibres or filaments. Such fusion can be achieved e.g. by calendering or through-air blowing or by ultra-sonic impact.

Finally, consolidation can be achieved by mechanical means (frictional bonding), like needling, stitching, water-jet entangling or a combination of these various means.

Customers needs can be further met by modifying or adding to the existing properties of the fabric through finishing. A variety of chemical substances can be employed before or after bonding or various mechanical processes can be applied to the nonwoven in the final stage of the manufacturing process.

The choice of the raw material and the final constituting fibrous element, the depositing of the fibres as a fibrous material of a varying density, the choice of consolidating and finishing means, all this creates a series of parameters which can be played with in order to reach the required properties. This confirms what was indicated earlier that nonwovens are engineered fabrics par excellence. When ingredients, web formation and consolidation are chosen in order to best meet the characteristics needed at the end application, then for sure, we have a winner.

0.3
Nonwoven properties and applications, including environmental considerations

Nonwovens are in fact products in their own right with their own characteristics and performances, but also weaknesses. They are around us and one uses them everyday, often without knowing it. Indeed they are frequently hidden from view. Nonwovens can be made absorbent, breathable, drapeable, flame resistant, heat sealable, light, lint-free, mouldable, soft, stable, stiff, tear resistant, water repellent, if needed. Obviously though, not all the properties mentioned can be combined in a single nonwoven, particularly those that are contradictory.

Their applications are multifold. Examples of their uses can be listed as follows:

- Personal care and hygiene as in baby diapers, feminine hygiene products, adult incontinence items, dry and wet pads, but also nursing pads or nasal strips.
- Healthcare, like operation drapes, gowns and packs, face masks, dressings and swabs, osteomy bag liners, etc.
- Clothing: interlinings, insulation and protection clothing, industrial workwear, chemical defence suits, shoe components, etc.
- Home: wipes and dusters, tea and coffee bags, fabric softeners, food wraps, filters, bed and table linen, etc.
- Automotive: boot liners, shelf trim, oil and cabin air filters, moulded bonnet liners, heat shields, airbags, tapes, decorative fabrics, etc.
- Construction: roofing and tile underlay, thermal and noise insulation, house wrap, underslating, drainage, etc.
- Geotextiles: asphalt overlay, soil stabilization, drainage, sedimentation and erosion control, etc.
- Filtration: air and gas, Hevac, Hepa, Ulpa filters
- Industrial: cable insulation, abrasives, reinforced plastics, battery separators, satellite dishes, artificial leather, air conditioning, coating.
- Agriculture, home furnishing, leisure and travel, school and office etc.

The origins of nonwovens are not glamorous. In fact, they resulted from recycling fibrous waste or second quality fibres left over from industrial processes like weaving or leather processing. They also resulted from raw materials restrictions e.g. during and after the Second World War or later in the communist dominated countries in Central Europe. This humble and cost dominated origin of course lead to some technical and marketing mistakes; it is also largely responsible for two still lingering misconceptions about nonwovens: they are assumed to be (cheap) substitutes; many also associate them with disposable products and for that reason did consider nonwovens as cheap, low quality, items.

There is nothing wrong in being a substitute; on the contrary if properties are similar and the cost and price lower, then the benefits to the user are obvious; there is better value for money. At the beginning the price differentials of nonwovens with regard to the products they did substitute was sometimes such that even some lessening of the properties still made the service acceptable. However, more often than none nonwovens turned out to be a substitute, not only with a cost advantage but with more and more additional or improved benefits to the user: think of interlinings, wipes, operation gowns, various air filters, etc. It is still to be hoped that the number of items (plastic, textile, paper, etc.) which nonwovens as flexible sheet structures should be able to substitute isn't finite yet and that the comparative cost and efficiency advantages of nonwovens remain. And of course, beyond substitution a part of nonwovens potential lies in their own creativity and increasing sophistication.

Not all nonwovens end in disposable applications. A large part of production is for durable end-uses, like in interlinings, roofing, geotextile, automotive or floor covering applications etc. However, many nonwovens especially light-weight ones are indeed used as disposable products or incorporated into disposable items. In our view this is the ultimate sign of efficiency. Disposability is only possible for cost-efficient products that concentrate on the essential required characteristics and performances and provide them without unnecessary frills.

Most nonwovens, disposables or not, are high-tech, functional items, e.g. with ultra-high absorbency or retention for wipes, or with softness, strike-through and no wetback properties for those used into hygiene articles, with outstanding barrier characteristics for medical applications in the operation room, or better filtration possibilities because of their pores dimension and distribution, etc. They weren't manufactured with the aim of disposability but in order to fulfil other requirements. They mainly became disposable because of the sectors they are used in (hygiene, healthcare) and of their cost efficiency. And disposability very often creates an additional benefit to the users. As disposable items have never been used before, there is then a guarantee that they do possess all the properties required as opposed to reused laundered fabrics.

At this point of the presentation, a ward maybe ought to be said about the environmental impact of the nonwovens industry and the waste management of its products. Even with over a million tonnes produced in 2000, the European nonwovens industry still remains a comparatively small industry (e.g. European textile industry 5632,000 tons in 1998, paper & board industry 90 million tons). The nonwoven manufacturing process itself is modern and straight forward, without presently obnoxious air or water emission, including for chemically-bonded fabrics, which make out presently about 10% of the total nonwoven production. As a modern industry its record is at least comparable, or better, than the paper or textile industries.

The apparent solid waste of the nonwoven industry in Europe can be estimated at 110–115,000 tons, of which 25% are raw materials. This quantity is minute in comparison to the total waste in Europe resulting from industry. (Manufacturing waste: 17% of 2,200 million tons/year – OECD/Eurostat 1999.) At least 50% of the nonwovens industry waste is recycled. A growing part of the remaining waste is turned to energy through incineration, or then sent to landfill, etc. This, however, is often dependent of the national circumstances and regulations, which vary sharply throughout Europe.

Nonwoven waste can also result from the disposal of used nonwoven products (i.e. post consumer waste). Such waste and quantities depend of the life-cycle of the nonwoven products themselves.

Of the 1,025,000 tons nonwovens produced in Europe in 2000, one can estimate that about 640,000 tons will appear as disposables or part of disposable items in the municipal waste stream of the year. Such amount makes about 0,30% of the total estimated municipal solid waste (MSW) (if the total waste collection figures remain the same). The rest of the production will be slowly distilled into the post-consumer waste stream as it comes to maturity.

There again waste quantities of nonwovens are not only comparatively low with regard to the paper or textile waste, but the nonwoven products themselves don't create more intrinsic problems than for paper or textiles. As such, nonwoven waste can be handled safely (as far as the nonwoven part is concerned) and all waste management solutions can be applied, at least in theory.

Finally, one should not overlook the many environmental benefits which result from nonwovens use, e.g. in air and oil filtration, oil absorption, protective work-wear, geotextiles, agriculture etc.

0.4
Development of the nonwovens industry

Nonwovens developed into an industry in the three main industrialized regions of the world, the USA, Western Europe and Japan, each of them contributing to the technological development of the nonwovens industry and of course fuelling its growth by new applications.

The categories where nonwovens are used in these main regions are broadly similar, although there remain sharp differences in consumers' expectation and needs. Coverstock types vary between Japan, the USA or Europe; medical items have a higher penetration rate in the States than in Europe; house-wrap is mainly a U.S. end-use; nonwoven interlinings and geotextiles developed in Europe before spreading worldwide, etc. Whilst in Western Europe nonwoven production amounted to about 63,300 tons in 1972, it had more than doubled within five years, and in 2000 reached 1,025,000 tons, growing by more than 10% in weight over the last year. This was achieved with a total manpower in the order of 16,000 people in 2000 which shows how highly capitalistic this industry is.

This production in Western Europe is achieved by about 130 companies. Despite some mergers taking place, and various companies becoming global players, the nonwovens industry at large remains an industry of medium to small companies, or of non-autonomous divisions or departments of larger groups.

The production per group of countries presently is as follows:

Table 0-1 Production of nonwovens in Western Europe (1983–2000)

in 1,000 tons

1983	*1985*	*1987*	*1989*	*1991*	*1993*	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*
231.4	272.1	338.2	414.0	480.6	554.5	646.4	684.4	759.5	836.0	909.8	1,025.9

Source: EDANA – European Nonwovens and Disposables Association.
Copyright: EDANA 2001.

Table 0-2 Nonwovens production by group of European countries

Countries	*1995*		*1997*		*1999*		*2000*	
	1,000 tons	*Million m^2*	*1,000 tons*	*Million m^2*	*1,000 tons*	*Million m^2*	*1,000 tons*	*Million m^2*
Scandinavia and Finland	100.5	2,922.4	115.8	3,250.0	131.5	3,661.8	137.8	3,569.9
U.K. and Ireland	56.6	1,326.7	63.4	1,550.5	78.7	1,796.4	91.0	2,154.8
France	67.1	1,784.4	75.6	1,919.9	93.2	2,348.7	98.5	2,613.4
Benelux	90.9	1,650.0	97.5	1,575.0	92.6	1,461.6	99.9	1,405.7
Germany	179.9	5,046.0	198.4	5,953.4	224.6	6,370.9	257.2	6,824.4
Italy	103.8	3,148.7	156.9	4,513.8	219.4	5,970.1	251.6	6,935.7
Others	47.6	903.0	51.9	1,128.5	69.8	1,629.4	89.9	2,267.5
Total	646.4	16,781	759.5	19,891.1	909.8	23,238.9	1,025.9	25,771.4

Source: EDANA – European Nonwovens and Disposables Association.
Copyright: EDANA 2001.

As far as Europe is concerned, it should be noted that from the start national references were of a secondary importance to the nonwoven companies, as the then production was larger than their national markets and outlets had to be sought beyond their national limit. (It is to be reminded that the speed of nonwovens production was from the beginning a multiple of what would be achieved through weaving or knitting.) This has remained so, and there aren't close links between the country of production and a company's market.

Germany and Italy are practically at par as the most important nonwoven producing countries in Europe, both in tones and in square metres. Germany though remains the largest market. Comparatively overseas figures are estimated at:

Reliable statistics are missing relating to the turnover of the nonwovens industry (without converting operations). European estimates put it at 4,100 million EURO for Western Europe in 2000; it is valued at 3,000 million US dollars for North America (Source: INDA). In Europe, the production of nonwovens per manufacturing process developed as follows:

Table 0-3 Worldwide production of nonwovens

Countries	*1997 (tons)*	*2000 (tons)*
Europe (Western)	759,500	1,025,900
Japan [1]	296,700	314,100
North America [1]	875,000	967,000
Others (estimates)	350,000	550,000
Total	2,281,200	2,857,000

[1] Contrary to Europe, Japan and USA data also include *most* needlepunched or stitchbonded fabrics.
Sources: Europe and others: EDANA.
Japan: MITI.
North America: John Starr (1997), INDA.
Copyright: EDANA 2001.

Table 0-4 Nonwovens production by manufacturing process in Europe (in 1,000 tons)

Process	*1991*		*1995*		*1997*		*1999*		*2000*	
	tons	%	*tons*	%	*tons*	%	*tons*	%	*tons*	%
Spunlaid [1]	197.3	41.1	267.9	41.5	318.0	41.9	368.1	40.4	409.1	39.9
Wetlaid	46.9	9.7	51.0	7.9	55.2	7.3	62.7	6.9	63.1	6.1
Drylaid [2]	213.9	44.5	278.7	43.2	326.6	43.0	401.8	44.2	459.5	44.8
Others [3]	22.5	4.7	48.8	7.4	59.7	7.8	77.2	8.5	94.2	9.2
Total	480.6	100.0	646.4	100.0	759.5	100.0	909.8	100.0	1,025.9	100.0

Source: EDANA – European Nonwovens and Disposables Association.
Copyright: EDANA 2001.

[1] Also includes other polymer-based processes e.g. meltblown, flashspun, orientated nets, perforated films, as well as composites of these fabrics (e.g. SMS…).

[2] Basically groups thermal and chemical bonding, plus needling or stitching only and hydro-entangled webs. Does not include any “airlaid papers”. The weight of adhesives, additives and similar chemicals has been taken into account (in addition to binders which always were included).

[3] Now essentially represents short-fibre airlaid webs.

Table 0.4 shows a sharp development of polymer-based manufacturing processes in the nonwovens industry. The drylaid process has continued its progression and remains the main one. It is however very varied, especially as far as bonding is concerned. In recent years, we have seen a sharp increase of hydro-entangling, partly linked to the development of all sorts of wiping applications. Short fibres airlaid fabrics, which are the latest newcomer, are also progressing fast. Although input of the wetlaid sectors more than doubled in that same time span, this pales into insignificance when compared to the other processes. The use of nonwovens per large groups of applications was in the last 10 years as follows:

One can see that as far as Europe is concerned, deliveries from the European industry to the hygiene sector have almost trebled in 10 years (in tonnes). They

Table 0-5 Deliveries of nonwovens per end-uses (in 1,000 tons)

End-uses	***1991***	***1995***	***1997***	***1999***	***2000***
Hygiene	131.4	210.7	252.2	324.9	341.4
Medical/surgical 1)	19.1	27.8	24.5	23.7	24.9
Wipes (from 1998) for personal care 2)	41.3	57.9	76.1	54.2	78.6
Wipes – others				47.5	73.9
Garment	10.2	6.2	14.1	10.1	12.5
Interlining	24.8	28.5	28.0	23.8	22.4
Shoe/leathergoods	14.0	19.9	18.0	20.6	19.3
Coating substrates		n.a.	7.6	11.3	14.5
Upholstery/table linen/household	46.0	39.1	29.8	51.1	59.3
Floor coverings		28.1	28.8	28.7	28.6
Liquid filtration	17.9	3.16 3)	22.0 3)	24.1 3)	28.2 3)
Air & gas filtration	8.0		10.3	14.2	15.8
Building/roofing	89.0	60.6	99.6	115.5	134.4
Civil engineering/underground		61.4	56.2	57.9	63.0
Others 4)	69.8	62.4	66.6	77.6	73.2
Unidentified		11.2	18.8	13.7	21.1
Total	471.5	645.4	752.6	898.9	1,011.1

Source: EDANA – European Nonwovens and Disposables Association.
Copyright: EDANA 2001 .
* This refers to production/deliveries of nonwovens produced in Western Europe.
1) Excludes medical wipes.
2) Includes medical wipes.
3) Includes fabrics for tea and coffee bags.
4) Includes as well electric/electronic applications, abrasives, battery separators and agriculture.

now make 33.8% of total deliveries. This partly reflects the increased penetration of disposable diapers in the European markets reaching over 90–95% or more of potential markets. Other causes are increasing exports of nonwovens for hygiene purposes or the wider use of nonwovens for various applications within the baby care sector (e.g. coverstock, leg cuffs, tapes, acquisition/distribution layer, textile backsheet, ...) or finally, the development of incontinence products and to a lesser degree of feminine protection items. Unfortunately, mainly due to the oligopolistic position of hygiene converters the nonwovens manufacturers haven't been able to reap sufficient profits in this sector.

Another sector, which in the last year took off dramatically, is the wipes sector, be it for personal, industrial or household applications.

Both sectors are relatively light-weight and therefore take up an even larger proportion of the nonwovens deliveries when expressed in m^2.

Finally the civil engineering (geotextiles) and roofing applications have trebled in 15 years time. On the other hand, the growth of nonwovens for medical purposes has not held its promises; levels of penetration don't compare to those in the U.S. The use of nonwoven interlining, although now dominant in the apparel industry, hasn't progressed as hoped in Europe, because of the difficulties of the European apparel sector.

Table 0-6 Fibres consumption in the nonwovens industry (in 1,000 tons)

Fibres/polymers	*1991*	*1995*	*1997*	*1999*	*2000*
Rayon viscose	53.5	56.0	67.3	78.1	92.5
Polyester	90.8	118.7	150.7	189.8	228.5
Polyamide	13.6	13.5	12.5	12.6	12.9
Polypropylene	209.2	311.3	369.9	442.3	491.4
Multi-components (1)	16.9	32.6	29.1	35.2	34.2
Other man-made fibres	35.2	38.8	44.7	51.8	59.7
Wood pulp	43.9	71.4	85.3	108.0	114.0
Natural fibres	16.7	16.4	13.4	14.5	15.6
Mineral fibres	4.2	5.9	6.0	6.5	6.7
Other materials		0.6	2.6	5.4	5.1
Total	484.0	665.2	781.5	944.2	1,060.6

Source: EDANA – European Nonwovens and Disposables Association
Copyright: EDANA 2001
The data relate to fibres used (including wood fibres) and to polymer granules turned into filaments during the manufacturing process (e.g. spunlaid) and for a smaller part to plastic (perforated) films. Fibres used include regenerated fibres.

1) In 1997, the definition of bicomponent and multi-component fibres has been made more accurate.

The increase in fibre production reflects the trends in the production of nonwovens. In the last 10 years, the use of polypropylene has more than doubled and is the main fibre or filament used in the whole nonwoven industry. The use of other fibres, which in the eighties seemed to regress, has picked up again as new technologies, or new applications develop and spread. On the other hand the use of wood pulp has increased sizeably and isn't at all limited to the wetlaid process. Other, mainly specialized, manmade fibres also made inroads. The use of natural fibres like cotton or wool in nonwovens remains minimal.

In 2000, polypropylene cut fibres made 37.9% of the total polypropylene used in the nonwovens industry, whilst polyester cut fibres made 61.9% of the polyester fibres used. Viscose was exclusively used as a cut fibre.

To round up this positive image one should add that the balance of external trade of the European nonwovens industry is positive. Despite their imperfection, statistics indicate that (Western) Europe exports more nonwovens than it imports, the surplus being in 2000 in the order of 83,000 tons and still growing. A deficit exists though vis-à-vis the United States where it is very much influenced by the trade policy of dominant U.S. companies with subsidiaries in Europe. Countries like the Czech Republic and Slovenia, and above all Israel, are now nett importers of nonwovens into the European Union.

0.5
Future perspectives

Questions however are being raised about the future of the nonwovens industry in Europe. Obviously growth isn't a problem as far as the rest of the industrializing world is concerned: compared to needs, the production and use of nonwovens, e.g. for hygiene or civil engineering application, has barely started there. But, isn't the nonwovens industry maturing in Europe? Are there novel speciality applications opening up that will relay the dominant hygiene (baby-care) end-use? Will it not undergo a fate similar to the European textile or apparel industry, which, for a large part, gave in to lower price imports from emerging markets?

We don't have any crystal ball but here are a few elements of answer. Technology hasn't stood still and large reserves of technological development for nonwovens no doubt still exist, especially within the European manufacturing equipment industry. The capital costs of entry have been brought down though to relatively low levels and newcomers do find it relatively easy to come in.

However the availability of production equipment is only part of the answer. Maybe more than in comparable industries, qualified manpower and know-how that exists in companies remains of paramount importance (and can be patented). Hence it is also a must that proper R & D departments are maintained within companies, or in sufficiently large research institutes, so as to exploit further possibilities which otherwise would remain ignored or neglected.

The nonwovens industry has induced transformation and discoveries not only in the equipment sector but also at raw materials and converting levels. As an example among many, the fibres for the nonwovens industry aren't identical to fibres for weaving or papermaking. Without a steady supply, at the right price, of fibres and polymers and an appropriate research and development of fibres specifically for the nonwovens industry a question mark could arise as to the future development of a dynamic nonwoven industry in Europe. But, on the other hand, the sheer size reached by the European nonwovens industry makes it more rewarding to develop raw materials for it, and this effect snowballs into better products.

Beyond efforts in reducing costs – e.g. in manufacturing waste – and increasing production speeds, there are still many reserves regarding the incorporated high-tech properties of nonwoven webs for which the European industry can keep its advantage: progresses in the regularity and uniformity of the web, at increasing speeds and diminishing fabric weight are only part of the answer in the race to keep the present advantages. The combination of multiple technologies into sophisticated composites is another one as long as the constraints of recyclability – as opposed to energy recovery – don't become excessive. The industry in Europe has also to position itself both vis-à-vis the world and its present or potential customers. Mergers are one of the attempted solutions, which can alter bargaining powers (and therefore price) and create opportunities. Such organizational changes though, shouldn't be detrimental to flexibility and response to the signals of NEW markets. Indeed sustained growth needs entry into new markets and requires also new products appropriate to the demands from such markets. It cannot be said that the markets for nonwovens in Western Europe have all been found and taken and have become a close and finite universe. (Also Eastern Europe and the Mediterranean basin are next door.) Nowadays nonwoven fabrics are quite different in properties, appearance, and costs from a decade or more ago. Society's expectations and products have also changed. Beyond incontinence which some see beaconing on the horizon as a future large outlet, new opportunities could be tapped (even if emerging markets aren't immediately very sophisticated or large), providing there is a will and a pioneering spirit ready for it. Therefore, in my view, increased nonwoven promotion and marketing investment by the industry are necessary in Europe in order to further boost off the second stage of the nonwovens rocket.

Part I

Raw materials for the production of nonwovens

Nonwovens are textile fabrics consisting of separated fibres which are arranged properly by means of enduse-oriented technologies. In order to guarantee serviceability of the finished product, they are bonded. For this reason the choice of fibres and possibly bonding materials is of special importance: This relates to fibre raw materials and fibre dimensions. As a rule they have a greater share in creating the specialities of the nonwovens than this is the case in textile fabrics made of yarns. The bonding agents can also have an impact on the quality of the nonwovens.

1
Fibrous material
W. Albrecht

Virtually all kinds of fibres can be used to produce nonwoven bonded fabrics.

The choice of fibre depends on
- the required profile of the fabric and
- the cost effectiveness

To produce nonwoven bonded fabrics
- chemical fibres of both cellulosic and synthetic origin as well as
- natural fibres and
- inorganic fibres

are mainly used

Because such a wide range of fabrics is either being developed or is already in production, it is impossible to name and describe all fabrics and fibres. The most important details will be provided below and the relevant literature will be cited. For more details the interested reader would be advised to consult additional reference material and to assess the importance of e.g. chemical fibres experimentally.

1.1
Natural fibres

1.1.1
Vegetable fibres

The most important constituent of vegetable fibres is cellulose, which is hydrophilic and hygroscopic. Apart from cellulose, vegetable fibres also consist of several other substances which affect their properties.

Cotton is the most important vegetable fibre used to produce nonwoven bonded fabrics. Table 1-1 shows the development of cotton production.

Cotton (Gossypium)
All varieties of cotton belong to the mallow family. To grow properly, the plants need moisture as well as dry heat alternately at the right times. Cotton is an an-

Table 1-1 Development of cotton production world-wide from 1981 to 2000

Year	*Quantity (tons)*	*Area (km^2)*	*Yield/area (kg/hectare)*
1981	14,995,000	330,690	471
1986	15,264,000	292,010	523
1991	20,805,000	349,390	595
1998	19,548,000	337,670	579
2000	~20,000,000	~335,000	~595

nual plant and grows to a height of approximately 1 m to 2 m. It grows fruit the size of walnuts which contain seeds covered with cotton fibre. The ripe fruit shells burst open and the cotton swells out in thick white flocks. The crop is usually harvested by machine, so that the cotton fibres are more likely to become contaminated than if harvested by hand. After harvesting, the seeds are removed with cotton gins and the cotton is packed into bales. The short fibres (linters) are removed by means of specialized machines and are used to produce a wide range of products, including the raw material for the production of cupro and acetate fibres. In fact, linters are also used in the production of nonwoven bonded fabrics.

Raw cotton contains:
- cellulose (80% to 90%)
- water (6% to 8%)
- waxes and fats (0.5% to 1.0%)
- proteins (0% to 1.5%)
- hemicelluloses and pectins (4% to 6%)
- ash (1% to 1.8%)

The quality of cotton and hence the grading depend on the following qualities:
- fibre length (10 mm to 50 mm)
- linear density (1.0 dtex to 2.8 dtex)
- colour
- purity (trash and dust)
- tensile strength (25 cN/tex to 50 cN/tex)
- elongation (7% to 10%)

The cotton fibres have to be scoured in an alkaline solution and/or have to be bleached to obtain the proper qualities and purity standard required for various purposes. To develop their typical fine sheen, the fibres have to be mercerised hot or cold. One of the most important characteristics of wet cotton is that it is some 10% stronger than dry cotton. Its good mechanical properties and serviceability are due to its structure.

As shown in Fig. 1-1 a and b, cottons shape and structure make it suitable for use for the production of nonwoven bonded fabric: cotton has a ribbon-shaped cross-sectional form, a spiral twist, a hollow structure, a high wet strength for a high module and it is hygroscopic.

Table 1-2 World production of cotton by countries and regions in 1997 and 1998

Country/region	*Quantity (tons)*	*Area (km^2)*	*Yield/area (kg/hectare)*
EU	465,000	4,980	934
Formermly USSR	1,587,000	25,510	622
– Usbekistan	1,150,000	15,050	764
China	4,400,000	46,000	957
Asia (without China)	6,156,000	138,650	444
– India	2,450,000	88,060	278
– Israel	53,000	290	1,828
USA	4,100,000	53,760	763
America (without USA)	1,040,000	23,840	445
Africa	1,797,000	44,790	401
– Egypt	350,000	3,730	937
Eastern Europe	3,000	140	231

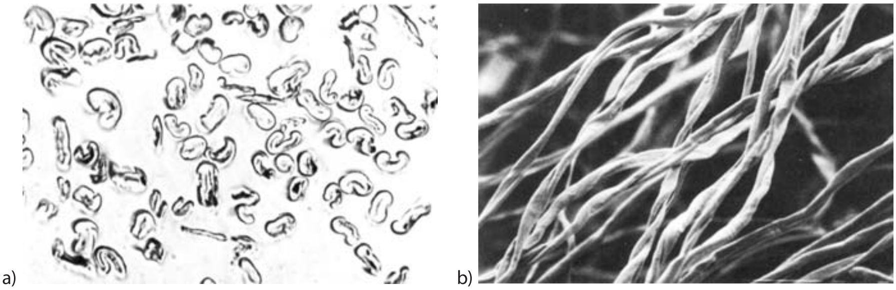


Fig. 1-1 a) Cross section, b) longitudinal section of cotton fibres

Thus its use for the production of nonwoven bonded fabrics met with a fair degree of success in the early years. Its success, however, faded quickly because of the impurities which affected the production and even the quality of the finished product. This problem could not be solved, for it is impossible to remove all impurities during the production process or counteract their effect. This technical problem caused the noted decline of cotton usage in the production of nonwoven bonded fabrics.

Jute (Corchorus)

Basically, two types of jute are grown to produce bast-fibre; with Bengal jute generally being preferred because of its pliability. The strands of fibro-vascular tissue from the inner cortex are prepared and turned into fibrous material in a special process. The quality of raw jute depends on the quality of the soil, the climate and roasting, and the method used to separate the bast from the cortex after it has been removed from the 3 m to 5 m long stems. To soften the vegetable glue (gliadin) in the ribbon of bast, the jute needs to be batched with softening oils and crushed repeatedly to allow further processing. The long bast ribbons are cut into pieces of 25 cm to 35 cm length with strong carders, second breakers, or special machines and are turned into mats.

Chemically, jute is a highly lignified fibre, which consists of:
- 60% cellulose
- 26% hemicellulose
- 11% lignin
- 1% proteins
- 1% waxes and fats
- 1% ash

with the substances cellulose and bastose forming a compound (lignocellulose, bastose), whose properties differ from those of other bast fibres. Jute is important for special usages of nonwoven bonded fabric. As it is quite inexpensive and has good physical properties it is predominantly used

- as the basic material for floor coverings
- as the base or intermediate layer in tufted floor coverings
- in filling pieces as, for example, in upholstery.

After the basic material has been subjected to months or years of wear, as it is the case in floor coverings, the surface deforms in the direction of tread, which must be considered when the floor is laid. The reason for this deformation is the rigidity of the individual fibres, which prevents them from altering their shape under pressure, so they slide off one another in course of time. Furthermore, it must be noted that jute may rot.

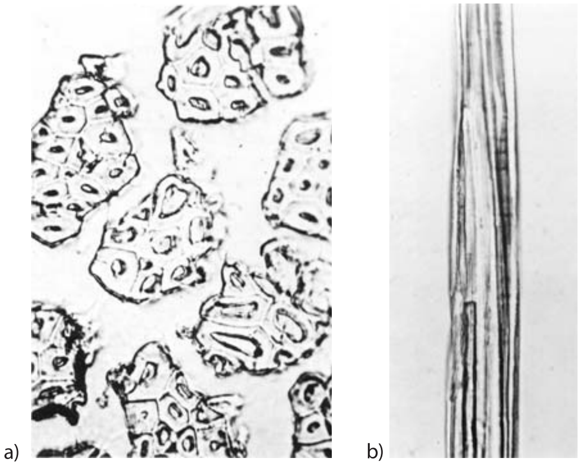


Fig. 1-2 a) Cross section, b) longitudinal section of jute

Flax (Linum usitatissimum)

Flax, an annual, is harvested shortly before the seed grows ripe for the extraction of fibre. The harvest comes to approximately 4,000 kg/ha, which yields 600 kg to 1,000 kg of raw flax are gained. The fibres embedded in the parenchyma of the stem in a high concentration are freed by retting. Then the flax is washed, dried and broken to loosen the brittle wood from the bast and to separate the fibres from each other. The wooden parts are removed by means of scutches (rotary crushing machines). Finally the fibres are combed by means of hackles. Flax typically has a high tensile strength and low elongation and crimp. It is also used for nonwoven bonded fabrics, mostly for the fabrication of filling pieces.

Manila hemp (Musa textilis)

Manila hemp is one of the mock or skereuchym bast fibres. It is derived by drying and beating the mock stems, which are in fact rolled leaf bast. The fibres are yellow to brown in colour, about 5 mm to 8 mm long and very firm, light and shiny. They have a very high wet strength and rot resistance (Fig. 1-3).

Manila hemp is used to produce tea bags and manila paper on adapted machines. The firmness of the fibres and their pectin content give these special papers their unique qualities.

Coconut fibre (Cocos nucifera)

Coconut fibre is obtained from unripe coconut fruit. The coconut is steeped in hot sea water, and subsequently the fibres are removed from the shell by combing and crushing. The raw fibres are between 15 cm and 35 cm long and between 50 µm and 300 µm in diameter. Coconut fibre is used to produce matting as well as coarse filling material and upholstery.

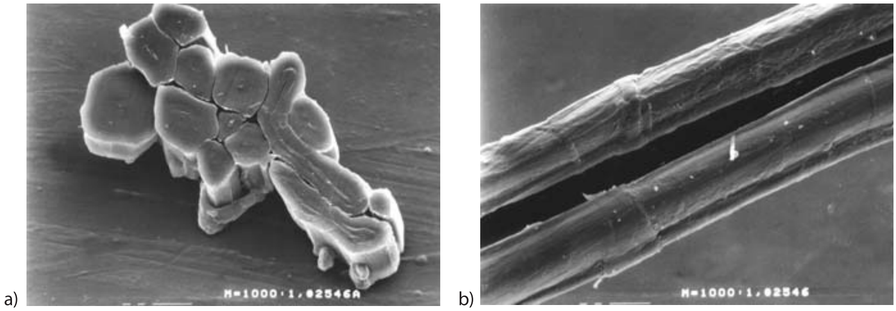


Fig. 1-3 a) Cross section, b) longitudinal section of hemp (photographs ACORDIS, microlaboratory)

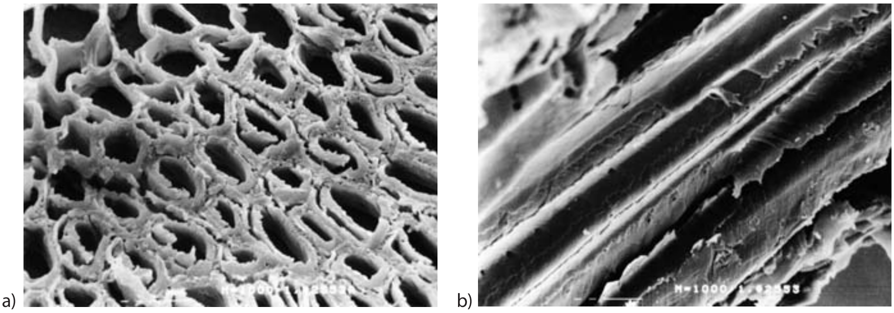

a) b)

Fig. 1-4 a) Cross section, b) longitudinal section of coconut fibre (photographs ACORDIS, microlaboratory)

1.1.2
Animal fibres

Sheep's wool (Ovis aries)

Of all the animal wool and hair, only sheep's wool is of any importance for the production of nonwoven bonded fabrics. As its price is high, it is used mainly in the form of reclaimed wool or cuttings. The variations in quality and the impurities in reclaimed wool as well as the chemical and physical properties determined by its provenance impose restrictions on its use.

The longitudinal section (Fig. 1-5 b) clearly shows the imprecate structure of wool. This structure is less marked in reclaimed wool, but for filling material, wadding and base layers it is still sufficient to guarantee a firm fabric. In chemical terms, wool is a suitably stiff and permanently crimped bicomponent fibre. The distinct variations in thickness are in most cases favourable to produce nonwovens. Like the traditional woolen felts, nonwoven bonded fabrics made of wool feature a relatively good shape stability, are high-bulking, and also good insulators because of the air trapped between the fibres.

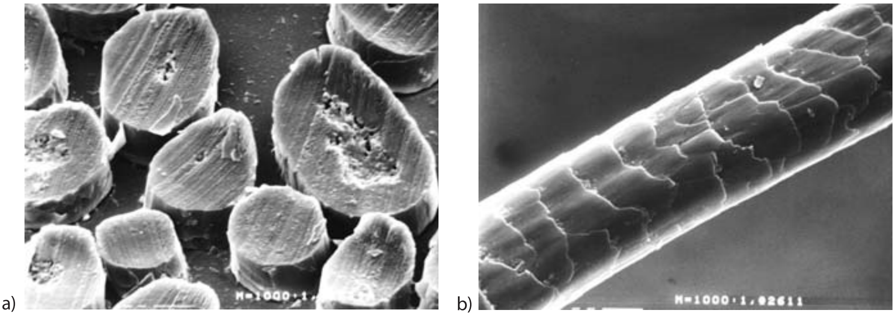

a) b)

Fig. 1-5 a) Cross section, b) longitudinal section of wool (photographs ACORDIS, microlaboratory)

Table 1-3 World production of wool and production by countries and regions

Year	*Quantity (1,000 tons)*	*Country/region*	*Quantity in 1996/97 (1,000 tons)*	*Contribution to total production in %*
1981	1,616	Australia/New Zealand	642	44.0
1986	1,789	China	150	10.3
1991	1,734	Eastern Europe	119	8.1
1996	1,456	Western Europe	108	7.4
		Uruguay	60	4.1
		Argentina	41	2.8
		South Africa	35	2.4
2000	~1,400			

Silk (Bombyx mori)

Silk fibre, composed of a fibroin core and a sericin casing, is relatively rigid because the sericin causes the filaments to adhere to one another. Since silk is expensive and scarce, it cannot play any sizeable role in the nonwovens industry. The remarkable tensile strength and fineness of silk fibres makes it suitable for the manufacture of special expensive types of papers.

1.2
Chemical fibres

Table 0-6 shows the importance of chemical fibres in the production of nonwoven bonded fabrics. The study of these fibres which follows focuses particularly on properties which are relevant to the production of web, the compacting into and the use of nonwoven bonded fabric. All other properties are described at length in numerous other publications. The significance of chemical fibres in the manufac-

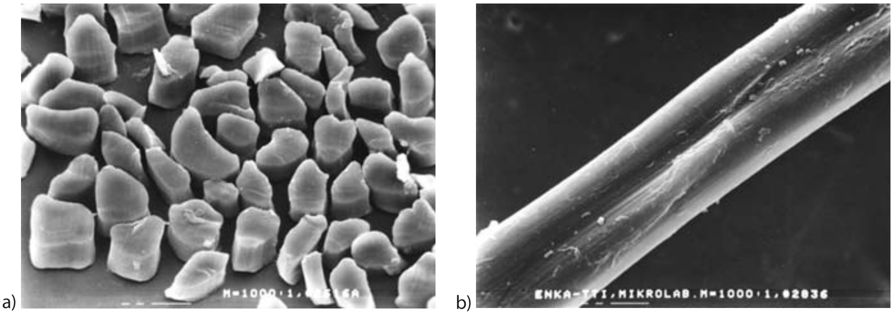


Fig. 1-6 a) Cross section, b) longitudinal section of silk (photographs ACORDIS, microlaboratory)

ture of nonwoven bonded fabrics has increased rapidly since the end of the 1950s. The evolution of chemical fibres was the decisive factor for the systematic development of nonwoven bonded fabrics for many new purposes.

1.2.1
Chemical fibres made from natural polymers

1.2.1.1 Cellulosic chemical fibres

Cellulosic chemical fibres can be used alone or mixed with other fibres to make nonwoven bonded fabrics. Generally, there are two methods to produce such fibres:

- the viscose process: regeneration of cellulose fibres from solutions of derivatives (e.g. viscose, modal fibres)
- the solvent process: regeneration of cellulose fibres from solutions of cellulose (e.g. cuprammonium, NMMO)

As fibres produced by the copper oxide-ammonia process have not as yet gained any importance in the manufacture of nonwoven bonded fabrics, the following section mainly deals with fibres produced by the viscose process. It must be noted, however, that some properties of fibres made by the copper oxide-ammonia process can be useful for the production and the application of nonwoven bonded fabrics. The Asahi Company in Japan, for example, seizes upon the conglutination tendency of cuprammonium fibres in the regeneration of the cellulose for making cellulosic spunbonded material without bonding agents.

1.2.1.2 Viscose staple fibres

By varying the conditions in the viscose process, e.g. the composition of the viscose and/or of the precipitating bath, or by using different methods of drawing the newly spun rayons, a number of basic fibres for spinning can be produced. Table 1-4 shows these basic fibres and their characteristic properties. Some of these figures are, however, more relevant to firms producing and processing yarn than to the nonwoven bonded fabrics sector, since the stability and elongation properties can hardly come to bear in nonwoven bonded fabrics. But the thickness of the fibre, the relative wet strength, the water retention value, the wet module and the suitability for mercerising may be of importance, directly or indirectly, to the production and the use of nonwoven bonded fabrics. The thickness (titre) of the fibres used determines a number of properties of the nonwoven bonded fabric that is to be produced:

- Distribution of the fibres in web formation: Provided that the mass per unit area is the same, the substance surface (covering power) is greater using fine fibres, but it may be more difficult to produce the even surface which is necessary for the frequently desired low mass per unit area.

Table 1-4 The most important viscose staple fibres and their properties

Properties		***Viscose staple fibres – basic types –***			***Modal fibres***	
		normal type	***highly crimped type***	***high wet strength***	***polynosic***	***high wet modulus***
Titre	dtex	1.3–100	2.4–25	1.4–7.8	1.7–4.2	1.7–3.0
Maximum tensile load in dry state	cN/tex	27–7.5	24–18	36–28	45–32	45–36
Maximum tensile load extension in dry state	%	16–30	20–30	21–28	8–14	14–18
Relative wet strength	%	60–65	60–65	65–80	72–65	75–65
Water retention	%	90–115	90–115	65–80	65–75	65–75
Suitable for mercerising		no	no	no	good	with reservations

- Surface of the fibre in the web or in the nonwoven bonded fabric: It can be relevant to bonding as well as to the use of the nonwoven bonded fabric (e.g. filter) and to the choice of the mass per unit area.
- Stiffness of the nonwoven bonded fabric: Although it depends more on the mass per unit area and on the type of bonding agent, it also depends on the thickness of the fibre.

Fibres with thicknesses of 1.0 dtex to 5.0 dtex, especially those between 1.7 dtex and 3.3 dtex, have shown good results in large-scale production. But both finer and coarser fibres are used for special purposes as well.

The maximum tensile load and the maximum tensile load extension are familiar characteristics of fibres. Whereas these properties are of great significance for yarn production and processing they are much less relevant for the production and the use of nonwoven bonded fabrics because they can hardly have an effect in the web itself and it is only the combination of fibre and bonding agent which results in the effective stability and elongation properties.

The cross tenacity and the hollow volume of the fibres are important for the wearability particularly of nonwoven bonded fabrics made with chemical bonding agents. These two properties also make clear why viscose fibres with high wet strength have become so important especially for interlinings: they show by far the greatest cross tenacity and hollow volume of all fibres featured in Table 1-4. The void volume allows the fibre to take up the substance displaced under flexural strain more easily.

The wet strength in the web or in the nonwoven bonded fabric can be relevant to both production and use, since this property may have effects on the generally continuous manufacture of nonwoven bonded fabrics in the wet state or during chemical bonding. Certain difficulties which used to occur during manufacturing have largely been eliminated through modification of the production process.

The water retention capacity affects the choice of production in different ways. First of all, it is of great importance in the wet production of nonwoven bonded fabrics, because a high percentage (~120%) or even very high percentage (~300%) leads to a more even suspension than a lower one (~90%). This is because the swollen fibres behave like a hose filled with liquid and thus do not form water coils. In this state, longer fibres can be used during the wet process and suspensions will last longer even if there is a low fibre-to-water ratio.

The high water retention capacity inevitably presents a disadvantage for drying. Nonwoven bonded fabrics made of such fibres are suited for use in various medical fields, particularly as a high water retention capacity in general goes hand in hand with a quick absorption of liquids. However, even whilst moisture is being absorbed, the high water retention capacity may cause a separation of liquids, if water is more quickly absorbed than larger and less mobile molecules, which may even settle on the surface. Furthermore, when drying, the swollen fibres predominantly contract cross-directionally, but also in the direction of the axis of the fibre. If the bonding system then has a lowered shrinkage rate, the bonding agent no longer completely surrounds the fibres and micropores will develop between the fibre and the bonding agent. Fig. 1-7 shows the water retention capacity of various cellulose fibres and may help with the choice of the right fibres and aid when determining what manufacturing process to use.

Although the dimensional stability and the stiffness of nonwoven bonded fabrics are contingent rather on the method of bonding than on the fibres used, the wet modulus has a certain impact on the properties. If small forces affect the fibre in the wet state, they can cause a relatively significant deformation, so the bonding system has to be even more loadable, which can be a disadvantage for the textile property of nonwoven bonded fabrics. The concepts "initial module" and "reference load" are explained in Fig. 1-8.

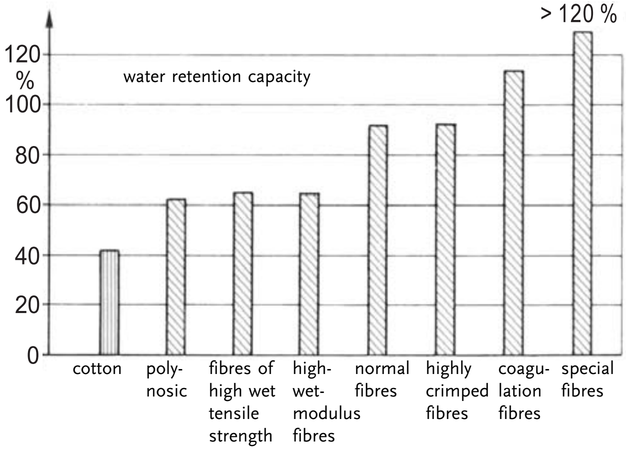


Fig. 1-7 Water retention capacity of different viscose staple fibres compared to cotton

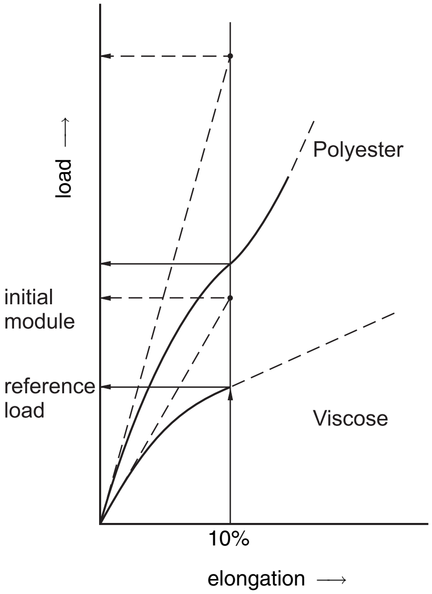


Fig. 1-8 The load extension graph for polyester and viscose fibres to determine the initial module and the reference load

When producing nonwoven bonded fabrics – especially when short fibres are used – the fineness ratio plays an important role. It is even more important when producing nonwoven bonded fabrics either with the wet method or with the aerodynamic process.

The following formula is used to express the fineness ratio:

$$\text{fineness ratio} = \frac{100 \cdot \text{length of a fibre}}{\sqrt{\text{fibre titre}}}$$

The fibre length is given in mm and the fibre titre in dtex.

That the importance of the ratio of the fibre length should not be underestimated is shown by an example: The fineness ratio of a 1.6 dtex fibre with a length of 6 mm is 474, whereas the ratio of a 10 mm fibre is already 791. Thus, higher fineness ratios can lead to problems in processing. However, these problems are often accepted to get the longest possible fibre length and to give especially nonwoven bonded fabrics made with the wet process the desired textile properties. This example shows very clearly how important it is to take into consideration not only the nominal ratings but also the individual effective ratings.

The reaction to mercerising is a criterion which has been adopted from conventional textile practice and which has to be adjusted to nonwoven bonded fabrics. It may be necessary to carry out alkaline processes while manufacturing nonwoven bonded fabrics. Similar treatment of nonwoven bonded fabrics is also possible after finishing. Once the mercerising properties have been established, we can predict how the fibres of nonwoven bonded fabrics will react in more or less concentrated alkaline media. Other important fibre properties – not stated in Table 1-4 – are the shape of the cross-section and the surface condition.

Fig. 1-9 shows the cross-sectional shape and the fibre structures of standard, high tenacity and high wet tensile strength viscose staple fibres. What is most striking is that the shape of the cross-section changes from lobate to rounded. The differences between the fibre types become evident in the processing of nonwoven bonded fabrics when various degrees of opening-readiness and draft properties can be observed. Furthermore, it is striking that the fibre structure varies throughout the cross-section. As an example, the more or less thick fibre sheet and the full-sheet structure of the wet crease resistant type can be cited. Additionally, the structures determine the rate of the water retention capacity illustrated in Fig. 1-7. This means that in practice the standard and the high wet strength viscose fibres react differently to liquids: the high wet strength fibres absorb liquids more quickly but at a lower retention rate.

This means that, as the substance of the high wet strength viscose fibres has a denser structure, the fibres have to have microvoids. These microvoids are also the reason for the high bending strength of this fibre type.

The higher substance density throughout the cross-section of the fibre together with the low module has further practical consequences, too. For instance, needling is made more difficult. Experts know how to avoid needle smash by choosing the right fibre: higher titres or the addition of standard viscose staple fibres guarantees the desired needling properties. In practice, the differences in structure between these two fibre types have the following effects on processing nonwoven bonded fabrics:

- Standard type: easy to process, has the standard properties expected of nonwoven bonded fabrics, low in price, readily available.
- High wet strength type: easy to process if appropriate care is taken, better finishing, better exploitation of the substance, better flexibility and consequently a noticeable improvement of wearability, restricted availability.

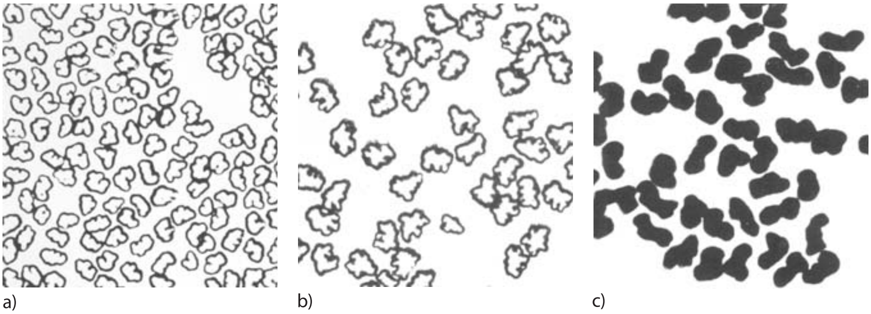


Fig. 1-9 Cross-sections of different viscose staple fibres: a) normal viscose, b) high tenacity viscose, c) high wet strength viscose

Fig. 1-10 shows cross-sections and longitudinal sections of highly crimped viscose staple fibres. The cross-section of highly crimped fibres is the same as that of normal fibres, but their skin is irregular, causing tension throughout the cross-section and in the end leading to crimping. Crimping is strong when the fibres are dry; however, it becomes less stable when fibres become damp and swell. In this way crimp disappears as soon as the water content reaches approximately 20%.

Certain kinds of paper, such as those used for cigarettes and vacuum cleaner bags, are made from polynosic fibres. Fibrillation (shown in Fig. 1-11) occurs rapidly when "milled" fibres are wet, it is important in the production of these papers and gives them their special properties. When combined with cellulose, such "milled" fibres increase stability considerably and facilitate adjustment for a specific porosity of fabrics. This also applies when fibres are wet. Lyocell fibres may be used for similar purposes.

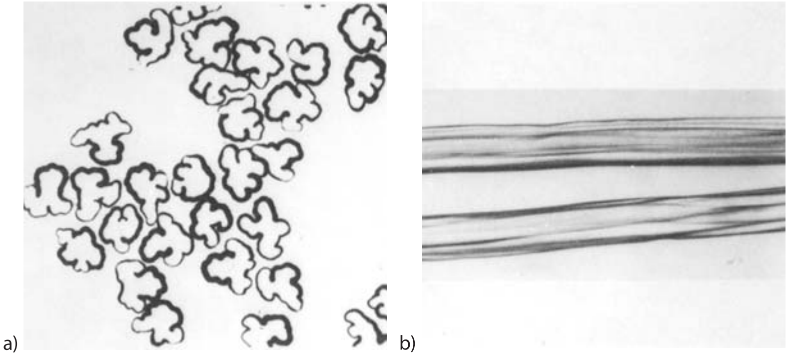


Fig. 1-10 a) Cross-section, b) longitudinal section of highly crimped viscose staple fibres

Fig. 1-11 Wet fibrillated polynosic fibres (lyocell fibres have similar properties)

Fig. 1-12 shows different crimp properties in viscose fibres. Crimping can vary considerably, as already explained in the section about the treatment of the fibre structure. Crimping is between 80 to 100 turns per 100 mm for normal dry staple fibres, while crimping is set at 120 to 140 turns for highly crimped fibres. It is not very difficult to obtain even higher crimping figures. However, problems arise in the production of nonwovens, since fibres get caught up in one another. It is important to note that the crimping frequency and amplitude figures apply only to dry fibres. This reservation is not valid for synthetic staple fibres.

The causes of crimping in chemical fibres are presented in Table 1-5 below. It shows that the processes adopted for cellulosic man-made fibres can also be used for synthetic chemical fibres, often with better results. It also shows that selecting the proper fibre makes it possible to achieve specific volume effects during the production of nonwovens.

Viscose filaments: Viscose filaments are produced with the same structural properties with which viscose staple fibres may be produced. However, their use in the field of nonwovens is not very significant.

There are two ways to produce such fabrics:

- Production immediately after spinning the filament. Spinnerets can be shaped in a specific way for this purpose. The production of such filaments requires additional modifications to ensure that the filaments guided in water or aqueous solutions are also mixed horizontally to give nonwovens the required transverse strength.
- Reeled, non-twisted, still damp or dry filaments can be drawn off and turned into nonwovens through air or liquids.

In practice, no market has been found so far for nonwoven bonded fabrics made from viscose filaments. The cost of the raw materials is rather high and the adjustment of the required transversal strength is relatively difficult for such nonwoven bonded fabrics. To a certain extent man-made filament yarns have been used successfully as fibre web to strengthen nonwoven bonded fabrics.

Cellulosic fibres for nonwoven bonded fabrics: Since the bonding of nonwoven bonded fabrics is a problematic production stage with downstream effects, the obvious thing to do was to try to develop suitable cellulosic bonding fibres. At first, ribbon-like fibres, used as glittering fibres in yarns, were processed on a trial basis.

Fig. 1-12 Crimping of different viscose staple fibres

Table 1-5 Crimping in fibres, yarns and fabrics

Causes of crimping	***Use***	***Permanency***
Mechanical distortion due to e.g. a) pushing b) gear treatment	Seldom in cellulosic man-made fibres, mainly in synthetic fibres	Cellulosic man-made fibres: poor Synthetic staple fibres: satisfactory to good
Mechanical distortion followed by setting due to: a) pushing/setting b) twisting/setting	Synthetic fibres	Very good
Tension in fibres due to: skin/core structure or some other bicomponent structure	High-crimped cellulosic and synthetic chemical fibres	Cellulosic man-made fibres: dry: satisfactory wet: poor Synthetic fibres: very good
Mechanical longitudinal distortion due to: a) filament breaking b) mixing with normal fibres c) shrinking in yarns or fabrics	Tapes of synthetic fibres mixed with shrinking natural or chemical fibres	Very good
Mixing of high-shrinking and normal-shrinking fibres with following shrink treatment	All kinds of high-shrinking synthetic fibres mixed with low-shrinking fibres	Very good

Fig. 1-13 shows cross-sections and longitudinal sections of such fibres. The ratio of thickness to width – often called axial ratio – is approximately 1:12 in the depicted type of fibres. It can still be increased up to approximately 1:40. The bonding effect of such ribbon-like fibres was evident, but not as strong as expected. For this reason hollow fibres were produced, as shown in Fig. 1-14. In non-bonded woven fabrics of the wet process type, they distinctively increased firm-

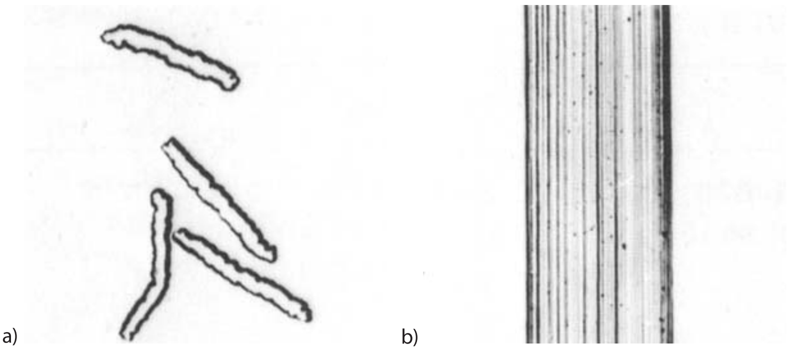


Fig. 1-13 Ribbon-like fibres with an axial ratio of approx. 1:12

Fig. 1-14 Cross-sections of hollow fibres

ness, without causing paperiness, as do many bonding agents. In forming nonwoven bonded fabrics, hollow fibres fault and enfold the fibres supposed to be bonded. Chemical bonds – so-called hydrogen bonds – such as those developing in the sheet forming of paper between the pulp fibres, do not occur when ribbon-like fibres or hollow fibres are used. But instead the water evaporating from the hollow space in the course of the drying process – as shown in Fig. 1-15 can “burst” the fibre and form a “double bonding area”.

Fig. 1-15 Bonding of nonwoven bonded fabrics with hollow fibres

Another method to produce cellulosic bonding fibres was found in the USA. BAR (Bonding Avisco Rayon) fibres consisted of a partly dissolved cellulose, were easily workable in the delivered state and on the wet fleece folding machine dissolved into a gel-like bonding agent that solidified the fibres, which were insoluble under these circumstances (Fig. 1-16). Nonwoven bonded fabrics produced in this way were particularly soft to the touch and had textile-like characteristics.

Lenzing company supplies another special fibre for the wet process. If a grafting process is used as long as the fibre is swollen, a very high water retention value is obtained and a special surface property is attained. A dispersibility of an un-

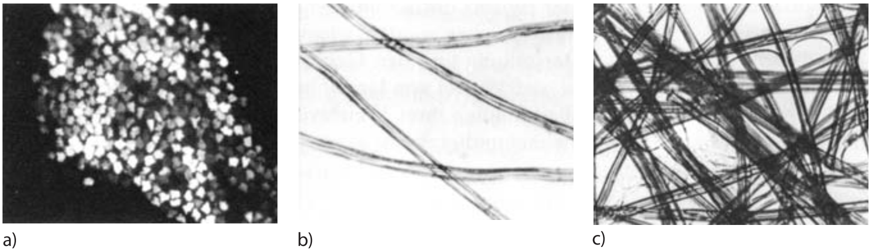


Fig. 1-16 BAR fibres: a) cross-section, b) longitudinal section, c) state after bonding

precedented magnitude is created. The suspensions are clot-free and are quite stable. This method also makes it possible to use longer fibres that make the finished product more textile-like (see water retention value). An additional method, the polybondic method, makes wet-bonded fabrics from fibres longer than 20 mm. For this process incompletely regenerated viscose staple fibres, which are more swellable than others, are used. A higher dispersibility and a more textile character of the product is obtained, because no chemical bonding is necessary.

Highly swellable cellulose fibres: Apart from the already briefly described method of producing fibres with a high water retention value, there are still other possibilities to produce fibres, which are swellable within broad limits and preferably contain cellulose. On the market, these fibres are often called “super slurpers”. To produce them, alkalised celluloses are etherified and crosslinked. Different etherification agents – ethylene oxide, chloricetic acid, methyl chloride and others – and different crosslinking agents, like mono- and multifunctional compounds, can be used. These highly swellable fibres, which are rendered insoluble by crosslinking in water and many other liquids, can depending on their structure possibly absorb several thousand per cent of their weight in water relatively quickly and also retain it relatively well. This effect makes these fibres especially suited for the use in sanitary articles and special technical fields. Such fibres are characterised by their extremely high water retention value (1,000% to 3,000%), the faster and higher absorption of the surrounding moisture (2 to 3 times that of cotton), the fact that they can be reused to absorb moisture and the ability to absorb water from saline solutions. These properties are highly dependent on the degree of crosslinking. Additionally, the production of nonwoven bonded fabrics and the manufacturing of the finished articles influence their serviceable properties because their properties are so distinct.

1.2.1.3 **Summary**

Cellulosic chemical fibres of all lengths and degrees of refinement and with clearly different properties, are at the disposal of the industry of nonwoven bonded fabrics. They are all characterised by the ability to absorb a fairly high amount of moisture. That recommends their use wherever this property is useful for the production of nonwoven bonded fabrics and/or the use of nonwoven bonded fabrics is even a precondition. The use of cellulosic fibres confirms time and again how advantageous it is for the production and the use of nonwoven bonded fabrics that the fibres are free from impurities and are easy to handle at all stages of processing.

1.2.2
Man-made fibres from synthetic polymers

The field of nonwoven bonded fabrics has become so broad that it includes nearly all kinds of existing fibres to some extent. However, specific fibre types have become predominant in certain areas within this field, a fact which will be explained in the sections below.

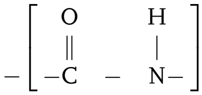
1.2.2.1 Polyamide fibres

Synthetic man-made account for the largest part of the raw material used in manufacturing nonwoven bonded fabrics. In this group of synthetic nonwoven bonded fabrics, polyamide fibres are the not only the oldest ones used in production, they also increase the serviceability of the product. This improved quality is of importance for various purposes, e.g.:

- where nonwoven bonded fabrics are subjected to frequent folding, as in the case of paper reinforced with synthetic fibres
- where exceptional resistance to abrasion is required, as is the case with needled floor coverings

The two main types of fibre are polyamide 6, usually known as Perlon, and polyamide 6.6, which is generally called Nylon to distinguish it from Perlon. The number or numbers after the word 'polyamide' indicate how many carbon atoms there are in each molecule making up the polyamide. The fact that there is only one number in one instance and two in the other shows that polyamide 6 contains only one basic module and polyamide 6.6 contains two, with six carbon atoms in each molecule. The figure also draws attention to the fact that the basic modules differ in size (e.g., polyamide 6.10 or polyamide 11 = Rilsan). Thus the number does not always have to be 6. A matter of course is that the properties of the polyamides change along with the different basic modules. Changes in water absorption capacity are important for the field of nonwoven bonded fabrics. Compared to the standard – polyamide 6 – it rises as the number of carbon atoms decreases and declines as the number increases. The other properties do not change in principle.

The bonds that link the basic molecules are the same for all polyamides. Macromolecules of this structure are referred to as polyamides because great numbers of molecules have to be present in order to form the macromolecules in the fibre.



$$-\left[-\overset{O}{\overset{\|}{C}}-\overset{H}{\overset{|}{N}}-\right]$$

Polyamide 6 is made from ε-caprolactam, and polyamide 6.6 from hexamethyldiamine and adipic acid. For fibre production, the resulting polyamide has to have the capacity to be spun into filaments, i.e.

- it must have the capacity to be melted without decomposing and to be forced through a jet
- the molten mass must be such that the filaments that are still ductile when formed do not break during cooling. Certain conditions must be met, one of them being a minimum prescribed length for the macromolecule

Fig. 1-17 shows the method of manufacturing melt-spun filaments as used for polyamide filaments.

The molten mass is forced through the holes in the spinneret by pressure pumps and metering pumps, after which it is pulled off in the form of filaments. They cool rapidly in the (air) blasting chamber and are then either baled or wound onto bobbins at a constant speed. The macromolecules are still randomly distributed in the filaments, which is why they are stretched so that molecules are more longitudinally oriented. Once they have this orientation, the filaments take on their characteristic physical properties and can be cut to the lengths needed to make the fibres. Then the filaments of staples are prepared to ensure that they retain their processing properties. This is how all of the fibres listed in Fig. 1-18 are produced.

The most important values for the physical properties of normal spun polyamide fibres are listed in Table 1-6, which covers various fibre thicknesses, degrees of lustre and cross-section forms. The term ‘normal’ is of great significance for nonwoven bonded fabrics, because:

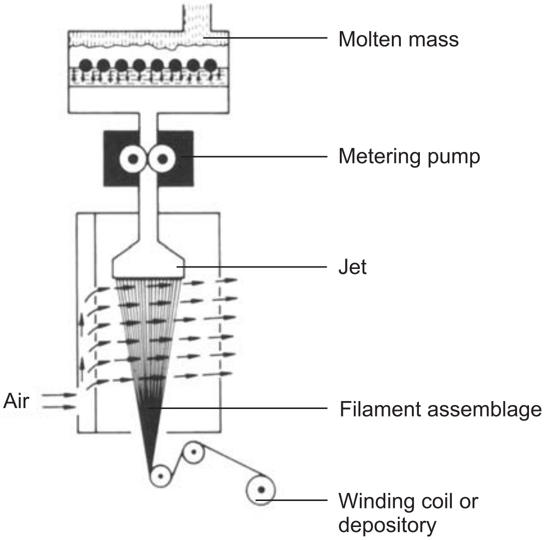


Fig. 1-17 Method of production of man-made fibres by melt spinning

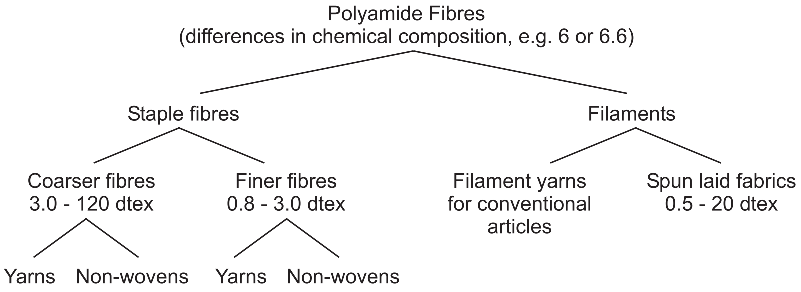


Fig. 1-18 Simplified subdivision of the polyamide fibres in production

Table 1-6 Typical values for normal polyamide fibre properties

Polyamide fibres	*Maximum tensile strength (cN/tex)*	*Maximum elongation (%)*	*Relative wet strength (%)*	*Water retention value (WRV) (%)*	*Water content at 20 °C and 65% rel. humidity (%)*
1.6 dtex/40 mm bright	50–60	45–55	80–90	10–15	4
3.0 dtex/40 mm semi-dull	45–55	50–60	80–90	10–15	4
17 dtex/80 mm semi-dull	40–50	65–75	80–90	10–15	4
22 dtex/80 mm semi-dull	40–50	55–65	80–90	10–15	4
35 dtex/100 mm bright prof	30–40	70–80	80–90	10–15	4

- copolyamide fibres can also be used (see the section on synthetic bonding fibres)
- the filaments used in spun laids are produced under different conditions than the textile or technical man-mades with regard to their production conditions (see Section 4.2.1)
- very strong fibres are not used at all in nonwoven bonded fabrics, whereas they are used in tarpaulins, conveyor belts and tyres, but
- fibres which react differently when dyed can be used together, for example in needled floor coverings

The term 'prof' used in reference to Type 35 dtex, 100 mm bright (Table 1-6) stands for 'profiled', indicating that the fibre does not have the usual round cross-

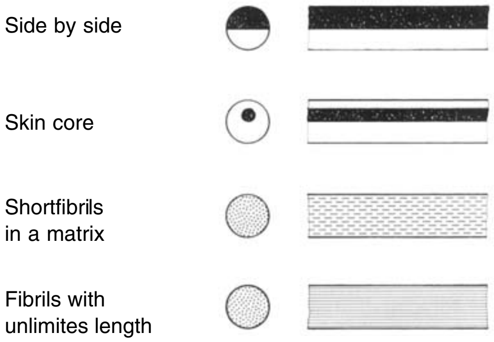


Fig. 1-19 Types of bicomponent structures

section. In this case, it is three-sided. Further information on cross-sections is given in the section on polyesters.

Other variations in melt-spun fibres are the result of bicomponent spinning, i.e., the combination of two more or less different raw materials. Such types are logically called bicomponent fibres. Fig. 1-19 shows a schematic diagram of bicomponent fibre structures.

These types can be varied even more widely by changing their form and the relative fibre proportions of their raw materials, thus producing different external effects. In this way, for example, side-by-side fibres can be made with considerable variations in their crimping or curling effect (frequency, amplitude, volume and permanency).

The core in skin/core fibres is not always to be found exactly at the centre or indeed in the same position over the whole length of the fibre. This likewise creates a tension in the fibre, which results in crimping. Far more important, however, is the fact that bicomponent fibre spinning technology enables polymers with different properties to be spun together, thereby producing fibres with a polyester core and polyamide skin, for example. In such a case, the core guarantees the dimension stability of the fibre and the skin ensures that the fibre will dye easily and well. The properties of bicomponent fibres are governed by:

- the two raw materials
- the relative quantities of the two components
- their arrangement within the fibre
- the thickness of the fibre

Fig. 1-20 gives a schematic representation of how bicomponent fibres are produced and explains how it is in fact possible to mix polymers in such a way as to make fibres other than the bicomponent fibres described.

If, for example, the melting points of the polymers being mixed are different, the component which melts at a higher temperature will solidify in the still-molten mass of the other polymer, which will set at a lower temperature. When the fibres are drawn, elongated inclusions are formed (Fig. 1-21 a). These may even be endless, i.e., they are present in the matrix as very fine filaments. Such fibres are exception-

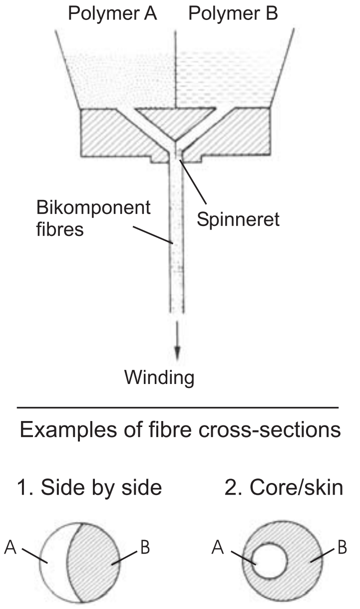


Fig. 1-20 Bicomponent fibre production process

ally stiff and display special physical and chemical properties. Especially in the case of nonwovens, bicomponent fibres open up new fields of application in which particularly large fibre surfaces in relation to their mass per unit area are required. Although relatively fine fibres can be manufactured for this purpose, they are practically impossible to handle at thicknesses of less than approx. 0.5 dtex. For this reason, spinning begins with bicomponent fibres with a total denier that supports the reliable production of fabrics, followed by the splitting of bicomponent fibres into their individual components through chemical or physical processes.

Ultrafine fibres are made by removing the matrix which holds the individual fibres together (Fig. 1-21b). These ultrafine fibres are similar in form to skin fibrils and can therefore be used in the manufacture of artificial poromeric leathers.

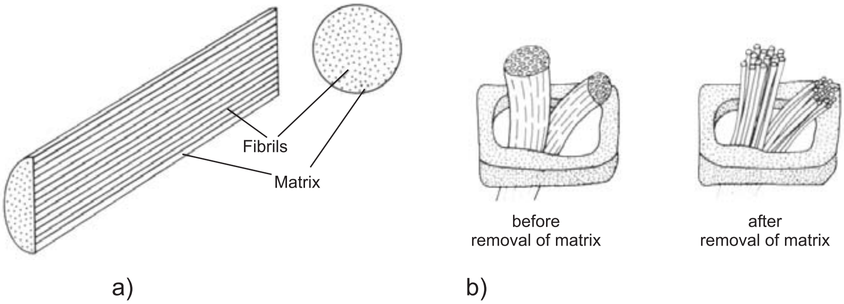
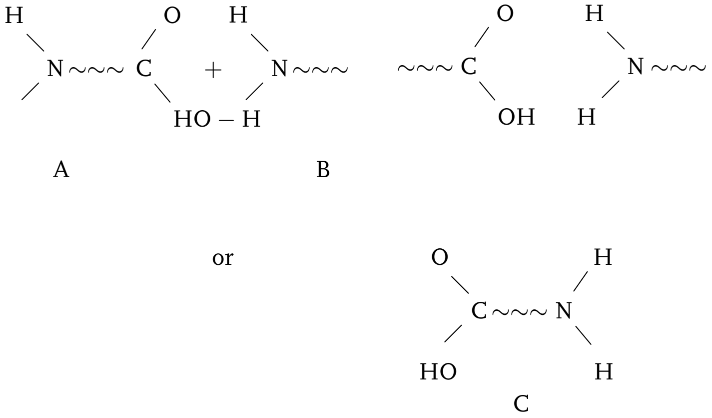


Fig. 1-21 a) Bicomponent fibre with fibrils of indefinite length in a matrix, b) bundles of ultrafine fibres before and after removal of the matrix

Other man-made fibres can also be produced by this method, which works most easily with melt-spun fibres.

Another way of modifying polyamide fibres is to vary the number of amino end groups in the macromolecule. If the two molecules ‘A’ and ‘B’ (see below) do not combine to form the amide group, the ‘free ends’ must be saturated in some way.



This can be done with water, for example, resulting in a molecule with an amino group at one end and a carboxyl at the other, as in C below.

The amino group is reactive, and it is well known for binding acidic dyes and other such textile auxiliaries. In the case of polyamide 6.6, which is formed from hexamethyldiamine (with one of these amino end groups at either end) and adipic acid, some of the molecules must have one or even two amino end groups. The number of amino end groups depends on the length of the molecule; but since in practice minimum and maximum molecule lengths are required for the manufacture of fibres, the direct addition of substances with amino end groups will also affect the reaction of fibres with specific dyestuffs (chemicals). The affinity to acidic dyes can thus be increased (deep type), reduced (light type), and even blocked (nontype). This makes differential dyeing possible, i.e., the use of such fibres in combination with others which have a ‘normal’ affinity to dyestuffs.

1.2.2.2 **Polyester fibres**

As its name indicates, this type of fibre consists of macromolecules of esters, which are chemicals made of acid and alcohol. If many of these basic molecules are joined, they will form polyesters. This description of the structure indicates that polyesters may develop from completely different acids and alcohols. Although this absolutely holds true, the term ‘polyester fibre’ generally comprises only fibres which consist of terephthalic acid and glycol. Fig. 1-22 illustrates the manufacture of polyester from different components. It also shows that it is not necessarily the acid that has to serve as basis, but that a simple, easily manageable ester, i.e. dimethylterephthalate (DMT), may be taken as well. A monomer, i.e. terephthalic acid diglycolester, develops by transesterification with the help of

a) from DMT and glycol
dimethylterephthalate + 2 glycol ⟶ diglycolterephthalate + 2 methyl alcohol
DMT DGT

n-diglycolterephthalates manufacture polyester by glycol splitting
DGT PET

b) from TPA and glycol
terephthalic acid + glycol manufacture polyester by dehydration
TPA PET

Fig. 1-22 Manufacture of polyester from a) DMT and glycol, b) TPA and glycol

glycol, which is a bivalent alcohol used for forming fibres. During this reaction the methyl alcohol needed for developing DMT is freed again and recovered.

By condensation (chemical condensation is defined as the fusion of molecules by dehydration or evaporation of alcohol; the term polymerisation means that molecules merge completely, as e.g. when polyamide 6 is formed) of terephthalic acid diglycolester, polymer develops, which is usually poured out in ribbons, cooled, chopped to small chips (granulate), remelted after drying and pressed through nozzles to produce filaments. The still liquid formed polymer may also be directly spun, if it seems appropriate. The newly spun filaments, which are still highly elastic, are wound or put into big containers and then stretched when hot. They may, however, also be directly stretched, i.e. without intermediate storage. When manufacturing spun fibres, the stretched filaments are towed, crimped, cut to the desired length and baled. In manufacturing nonwovens, spun polyester fibres are more important than filaments (see Table 1-7). Furthermore, spun-laids made of polyester filaments meet a ready market and are being developed further.

Table 1-7 Selection of available spun polyester fibres

Spun polyester fibres	***Type***	***Thickness in dtex***
Normal fibres	Fine fibre type	1.0–2.4
	Wool type	2.4–5.0
	Filling type	3.3–22
	Carpet type	6.7–17
Low-pilling fibres		1.7–4.4
High-shrinkage fibres (classical and linear)		1.7
Fibres with abnormal dye affinity (low-pilling at the same time)		4.4–17
Bicomponent fibres		3.0–17
Bonding fibres		1.7 and coarser
Flame-retardant types		1.7–4.4

The lengths of cut are adapted to the respective manufacturing procedure. Fibres are available in different degrees of lustre and cross-sectional forms.

As shown in Table 1-7, polyester fibres may be modified in many different ways. That is why they have been made to suit a wide range of different purposes and uses. It is, however, difficult to give the basic properties of polyester fibres without indicating the name of the respective type of fibre. Thus it should only be mentioned that, in general, polyester fibres

- may be used for a great number of purposes because they
- may be relatively easily adapted to their intended use
- while retaining all their serviceable qualities,
- especially their dimensional stability as well as their high light and weather resistance.

In addition to these generalised but characteristic features, Table 1-8 contains figures for some properties of the most important types of polyester fibres.

In the stretching process, the molecules come to lie parallel to one another, which causes inner tension in the fibres. Because of this tension, the fibres may shrink again when heated, if they are not held tight at both ends. Therefore the stretched, unfixed fibres are called unstabilised. If the molecules now lying more in parallel to one another are able to attain optimum alignment as a result of heating, the fibres will not shrink any further in subsequent processing. Such fibres are referred to as stabilised or fixed.

Fig. 1-23 shows that tension-free stabilisation also influences the tensile properties of fibres. These properties, however, remain unaffected, if the stabilising process is executed under tension. The tensile strength graph for the stabilised type in Fig. 1-23 is supposed to show unstabilised fibres that were able to shrink freely when subjected to heating. Shrinkage on boiling is up to 10% in unstabilised fibres, while it is from about 2% to less than 6% in stabilised fibres depending on the conditions of stabilisation (temperature, time and tension). Unstabilised fibres

Table 1-8 Important properties of the basic types of polyester fibre

Property		***Fine fibre unstabilised***	***Fine fibre stabilised***	***Wool type normal***	***Wool type low-pilling***
	dtex/mm	1.7/40	1.7/40	3.3/60	3.3/60
Maximum tensile load	cN/tex	55–60	55–60	45–55	36–42
Maximum tensile load extension	%	24–30	22–28	40–50	35–45
Wet strength (relative)	%	100	100	100	100
Shrinkage on boiling	%	4–7	1–4	1–3	2–3
High temperature shrinkage	%	6–9	2–5	2–5	3–5
Hot air shrinkage	%	16–18	5–7	9–12	10–12
No. of abrasion revs		4,000–6,000	3,000–4,000	3,500–4,500	2,000–2,500

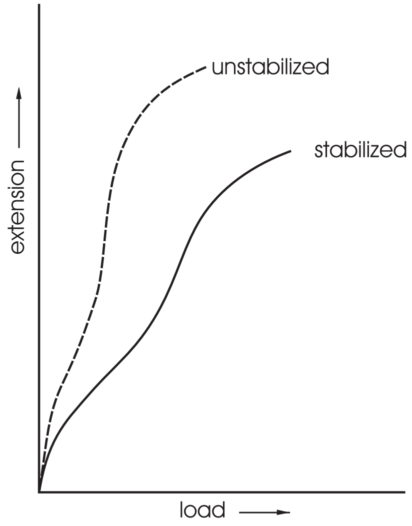


Fig. 1-23 Load-extension graph of unstabilised and stabilised PET fibres

are often used for the manufacture of nonwoven bonded fabrics, as they will shrink a little further in finishing. Thus the final product will be appropriately close with a little more volume. After such treatment the fibres, which now will not shrink any further, have also got the desired dimensional stability.

Shrinkage in polyester fibres may be directly influenced by varying the physical conditions (how the fibres are stretched) or chemical conditions (use of copoly-esters) during manufacture. Such polyester fibres are called polyester high shrinkage (HS) fibres. In Fig. 1-24, which illustrates their characteristics, shrinkage is completely different in each of the two HS types depending on temperature.

The physically modified fibres begin to shrink at 50 °C to 60 °C, with maximum shrinkage at 100 °C. Furthermore, the dotted line between points A and B shows that further shrinkage is blocked when heating is interrupted and continued later on, i.e. shrinkage will come to a halt at point A if the temperature is increased to

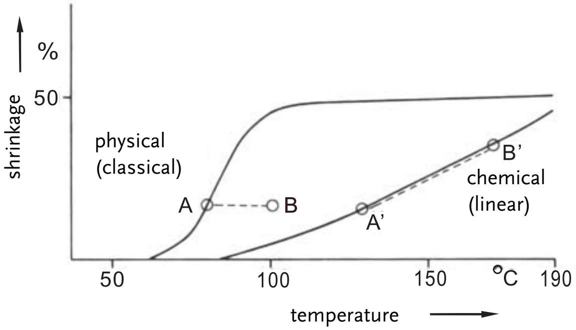


Fig. 1-24 Shrinkage characteristics of different PET HS fibres

e.g. 100 °C. In chemically modified fibres, the conditions are totally different. The copolymers added to the polyesters at first block shrinkage up to about 100 °C. Then, however, they even promote shrinkage and, in addition, prevent it from being blocked. This is indicated by the dotted line from A′ to B′. When using this type of fibre, it is thus possible to achieve a certain degree of shrinkage by changing the temperature accordingly.

In textile practice, the available shrink power is even more important than the measurable shrinkage of individual fibres in a tensionless state. Above all, the shrink power is the factor which makes it possible to surmount the resistance to distortion of the added fibres which shrink little or not at all, thus allowing these fibres to be crimped so that the yarn or fabric will be of the desired volume. Table 1-9 gives figures for shrinkage and shrinkage power of various types of Diolen spun fibre. Both properties are very important for the manufacture of nonwovens.

The cross-sectional form of melt-spun fibres may be altered fairly simply by using nozzles with appropriately shaped holes. Normally the nozzle holes are round, which makes it possible to obtain almost round fibres, as shown in Fig. 1-25.

The photograph of the slightly bent fibre below, however, reveals two further aspects which are essential for the manufacture of nonwovens. The smoothness of the surface will certainly not improve the adhesive power of thin bonding films, and the folds on the inside of the curve will, in addition, soon loosen any not firmly adhering bonding agent.

Fig. 1-26 shows various cross-sectional structures of melt-spun fibres: three-lobal, round and hollow. Apart from that, other shapes such as four-, five-, six- and eight-lobal as well as ribbon shaped are used quite frequently. Solid fibres with their different cross-sectional shapes fulfil two interesting demands that the end product makes on them. Firstly, they are chosen for a certain visual effect. Especially the outer surfaces and the degree of transparency determine the amount of light reflected and absorbed and thus the appearance of the textiles manufactured from these fibres. Secondly, the stiffness of fibres depends on the cross-sectional shape, which influences the texture and volume of fibres as well as the integration of the individual fibre into the whole fabric. These properties are also taken

Table 1-9 Shrinkage properties of various types of Diolen spun fibre

		Hot air 3′ 190 °C		***Boiling water 10′***	
	dtex/mm	***Shrinkage (%)***	***Shrinkage power (cN/dtex)***	***Shrinkage (%)***	***Shrinkage power (cN/dtex)***
Diolen 12	1.7/40	5	–	2	–
Diolen 11	1.7/40	12	–	8	–
Diolen 21	3.3/60	6	0.025	2	–
Diolen 31	3.3/60	50	0.045	45	0.065
Diolen 33	3.3/60	50	0.055	6	0.060

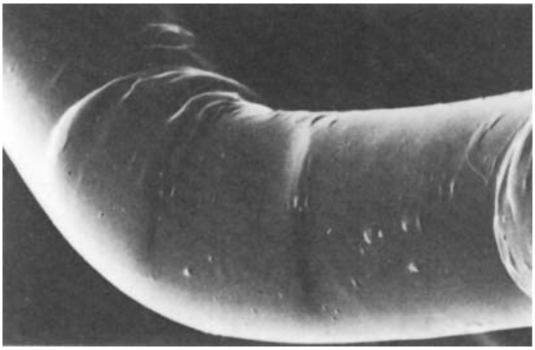


Fig. 1-25 Scanning electron microscope photograph of a PET fibre

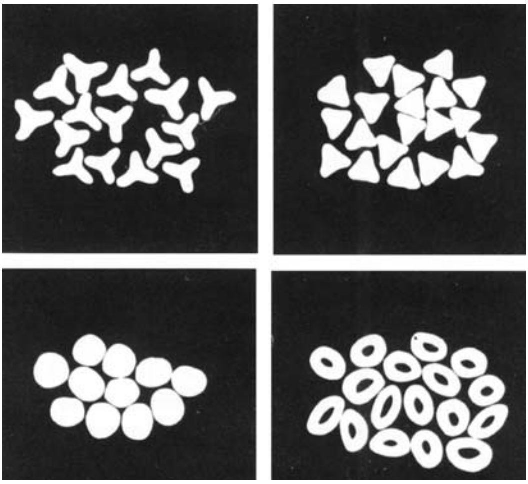


Fig. 1-26 Some cross-sections of PET fibres

advantage of in needled floor coverings, where the use of profiled fibres helps to create a subtle sheen and makes the material pleasant to walk on.

As hollow fibres provide much volume and increased stiffness compared to solid fibres, the end product will be lighter in weight. Depending on the size of the tube, the density of the fibres is proportionally lower than the density of the substance (1.38 g/cm^3). The tube extends all throughout the fibre, as is shown in the longitudinal view of Fig. 1-27. The diameter of the tube can be modified; it can amount to up to 20% of the cross-sectional area. Because of varying conditions during manufacture, the tubes are rarely perfectly round. When equal quantities of dye are absorbed, hollow fibres appear to be slightly darker than round solid fibres.

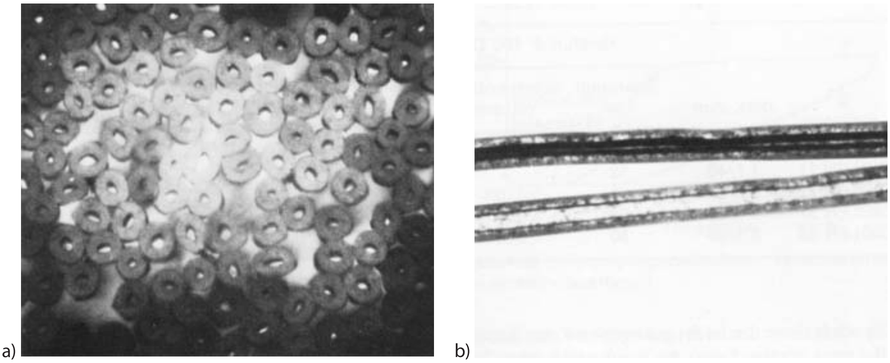


Fig. 1-27 Hollow polyester fibres: a) cross-sectional view, b) longitudinal view

Fibres resistant to pilling, or to be more accurate, low-pilling types are another type of polyester fibre which is of some importance also for manufacturing nonwovens. Pilling in textiles means that individual fibres which are fairly well integrated into the whole fabric are pushed outwards when they are subjected to frequent bending, abrasion or strain, and subsequently form a loop with their middle parts. If this effect continues, the loop connects with adjacent fibre ends, and together they develop pills or little knots (see Fig. 1-28).

Since especially in nonwoven bonded fabrics the individual fibres cannot be firmly integrated by twisting, as in the case of yarns, the problem should be solved by the right choice of fibres or by good bonding in the relatively few cases where pilling is detrimental. Table 1-10 lists different types of polyester fibres to show how much man-made fibres industry can influence pilling. When compil-

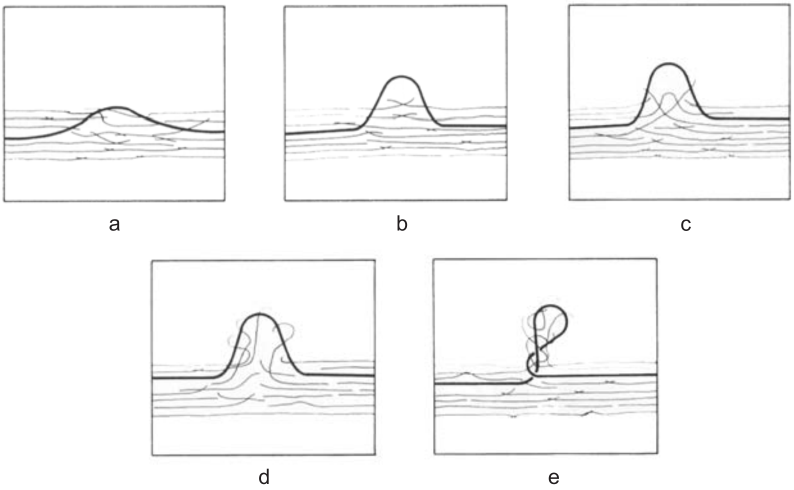


Fig. 1-28 Diagram of how pilling is caused

Table 1-10 Characteristic test figures for four different polyester fibres

Fibre types with round cross-sections		*Normal*	*Hollow*	*Pill-resistant*	*Super pill-resistant*
Fibre characteristics initial state					
Thickness	dtex	3.3	3.3	3.3	3.0
Maximum tensile load	cN/tex	50	45	40	30–33
Maximum tensile load – extension	%	35	40	45	32–37
Relative loop resistance	%	95	90	90	80
Bending resistance	turns	150,000	150,000	50,000	900–1,300
After four hours of high-temperature dyeing					
Thickness	dtex	3.6	3.6	3.6	3.0
Maximum tensile load	cN/tex	45	40	35	22
Maximum tensile load – extension	%	35	40	40	25
Relative loop resistance	%	85	80	80	70
Bending resistance	turns	70,000	120,000	20,000	1,000

ing this list, a clear distinction was made between the initial state of the fibres and the state in which the fibres are in a textile ready for use. The four hour high-temperature dyeing, which is part of testing, should comprise all possible finishing processes, including the chemical bonding in nonwoven bonded fabrics.

Table 1-10 clearly shows that mechanical and technological properties of fibres can be altered by modifying the cross-sectional shape and by adding copolymers (super pilling resistant). It is important to reduce flexing resistance so as to decrease pilling.

When pills are about to be formed, the fibres that have been pushed or pulled out should preferably break off, a circumstance which depends on maximum tensile load and elongation behaviour. – Evidence gained from experience shows that in the finished product, super lowpilling fibres should have a thickness/maximum tensile load ratio of 30 cN/tex as well as a maximum load extension of 35%. Fig. 1-29 illustrates the effects that can actually be achieved in similarly constructed plain woven materials made exclusively of one type of fibre.

The curves of the graph show that pills are formed when fabric is exposed to abrasion, which is also the case for wool. The number of pills developed per unit area, however, varies considerably depending on the type of fibre. If abrasion continues after the maximum number of pills per unit area has been reached, pills will break off. Therefore the total number of pills will decrease, despite the formation of new ones. If normal polyester fibres are used, still many pills will remain visible on the fabric, whereas in the other three types of fibre, pills will break off almost entirely or even entirely. Finally, also those polyester fibres should be mentioned that take dyes in a different way. The ability of such fibres to take dyes is improved and thus they will absorb the dye more quickly and more intensely. In

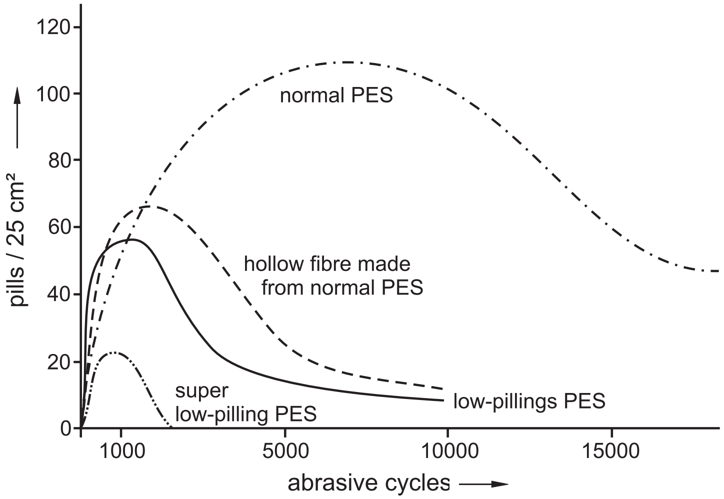


Fig. 1-29 Pilling curves for normal and modified polyester fibres

addition, types of fibre that take basic dyes as do polyacrylonitrile fibres are also important. For that purpose acidic groups are integrated into the fibre substance. The remaining polyester substance of the same fibre can, however, also absorb dispersion dyes just like normal polyester. This explains why no true differential dyeing is possible when polyester fibres with an affinity to normal and basic dyestuffs are mixed.

Polycarbonate fibres are a special kind of polyester fibre. Polycarbonate is the polyester of carbonic acid and is made from bisphenol A and phosgene. The fibres can be spun either dry or wet, and their density is about 1.2 g/cm^3. As polycarbonate is very heat-resistant and non-flammable, it is used in other fields, too, e.g. in air and gas filtration. Other important features are good electrical insulation as well as low water absorption.

Polyolefine fibres

In contrast to paraffins, olefins are unsaturated hydrocarbons. Therefore it is relatively easy to put them together to molecular chains. Although there is a great number of olefins, a fibre expert only thinks of polyethylene or polypropylene when talking about polyolefins. Both products are well-known as raw materials for the production of wrapping films and sheetings, containers and mouldings. The basic material is either ethylene or propylene, which occur as by-products of oil distillation or a special cracking process. Polymerisation is carried out by a high or low-pressure method using special catalysts, whereas spinning and making into fibres is done by melt spinning as for polyamide and polyester fibres. Polyolefins can also be made of films which are produced by melt spinning, as well. That is why fibre experts are trying hard to turn cast or blown-extruded films within a continuous process into fibre form, to put the fixed widths of the produced film fibres together to a yarn and to wind it immediately afterwards. The first stage of this method can also be used to produce nonwoven bonded mats. The raw materials that are most frequently employed for this process nowadays are low-pressure polyethylene and polypropylene. Increasingly, polymers which have been polymerized with the help of metallocene catalysts are processed. One of the remarkable features of these polymers is the greater uniformity of their macromolecules, which simplifies the processing. The respective raw material is melted in an extruder and forced through

- slot nozzles (see Fig. 1-30) or
- ring nozzles (see Fig. 1-31)

to form either plain films or different kinds depending on whether profiled nozzle lips or nozzle rings are used.

The shape of the nozzle determines whether

- flat films or
- tubular-blown films, which are cut at a later stage, are produced.

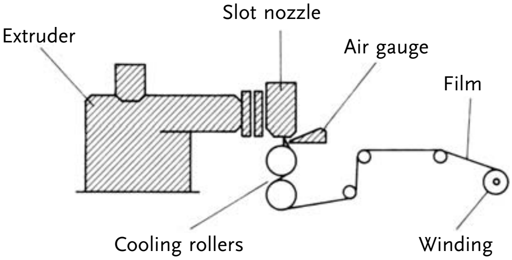


Fig. 1-30 Flat sheet extrusion with cooling rollers

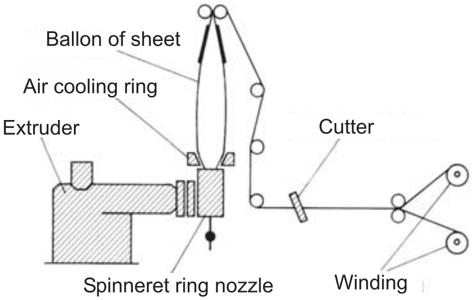


Fig. 1-31 Blow (extrusion film)

Further stages may vary, depending on the way the film has been made:
- cutting the films into narrow stripes (flat threads)
- splicing, controlled or uncontrolled, of the distended films
- splitting of the films that have been profiled during the processing
- fibrillation of multicomponent films

In order to produce cut flat fibres the films can be

- cut first and the resulting flat fibres then stretched monoaxially, or the films keeping
- constant width
- stretched first and then cut

Splicing of the stretched films can be done

- mechanically, when dealing with highly stretched films made of polypropylene which have a high melt-flow index by brushing, rubbing, using air jets or ultrasound, all of which lead to an uncontrollable and practically unrepeatable splitting up of the films longways;
- controlled mechanically by using a roller covered with fine needles and rotating in the direction of the film feed;
- uncontrolled, partly chemical, partly mechanical. In this case an additive is put into the raw material of the films. This additive, if statistically distributed inside the film, produces irregularities that simplify mechanical splicing at a later stage.

The splitting of profiled films leads to regular network-like fabrics which can be either used as they are, bunched together into “filament yarns” or processed into webs.

In case that two or more polymers are
- mixed before extrusion or
- put on top of one another in layers,

they are called multicomponent films.

When these multicomponents are fibrillated, the result naturally depends on the structure of the film. As for the mixed polymer films, their fibrillation tendency determines the type of polymer used, the proportions of the mixture and the distribution. It is worth testing the fibrillation tendency of the respective film. The easiest way to do that is to pass the film at constant tension over a small roller covered with needles. In this way, a split factor can be calculated. The higher it is, the easier it will be to achieve fibrillation in the film. Fig. 1-32 shows a basic example of the interdependence of split factor and proportion of mass.

How strongly the fibrillation tendency depends on the polymer mixture is additionally influenced by the stretch factor of these films. Three examples in Fig. 1-33 show these relationships.

When fibrillating films consisting of two or more layers, one has to assume that the individual components have a different shrinkage behaviour, which will affect both the processing and especially the crimping of fibrous structures. When producing multicomponent films by means of lamellar extrusion, also known as

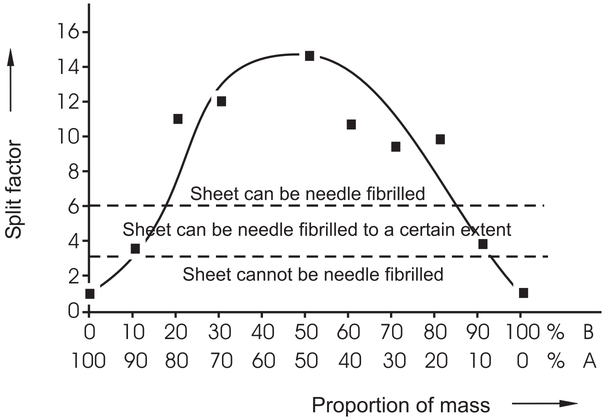


Fig. 1-32 Dependence of the fibrillation tendency on the polymer mixture

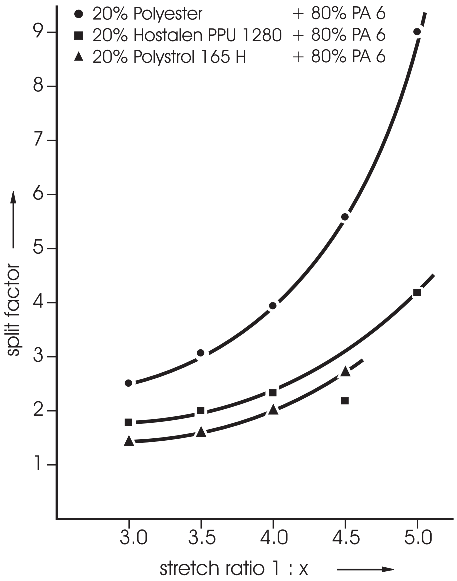


Fig. 1-33 Dependence of the fibrillation tendency on the second polymer and the stretch ratio

"the Rasmussen principle", two incompatible polymers are extruded through the special nozzle shown in Fig. 1-34. Cutting produces ribbons with thin layers, which split when stretched.

Fig. 1-35 shows how the components can possibly be arranged and when a third component, a binder, is added, sandwiches are produced. Their multilayered structure makes the sandwiches self-crimping.

In practice, fibre networks, as i.e. shown in Fig. 1-36, always develop when the film is turned into fibres, unless special cutters are used. The structure of these fibre networks makes them well suited for use as open webs.

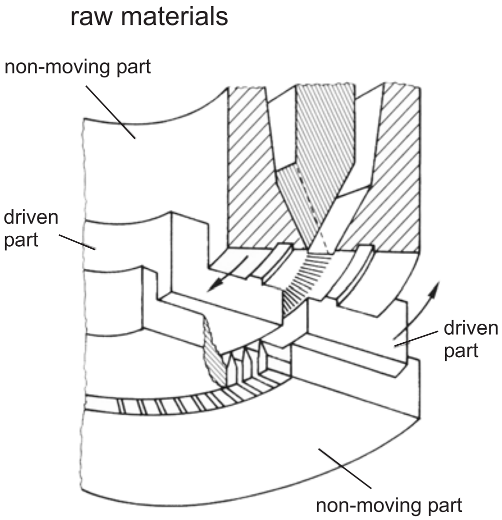


Fig. 1-34 The Rasmussen principle of nozzle construction

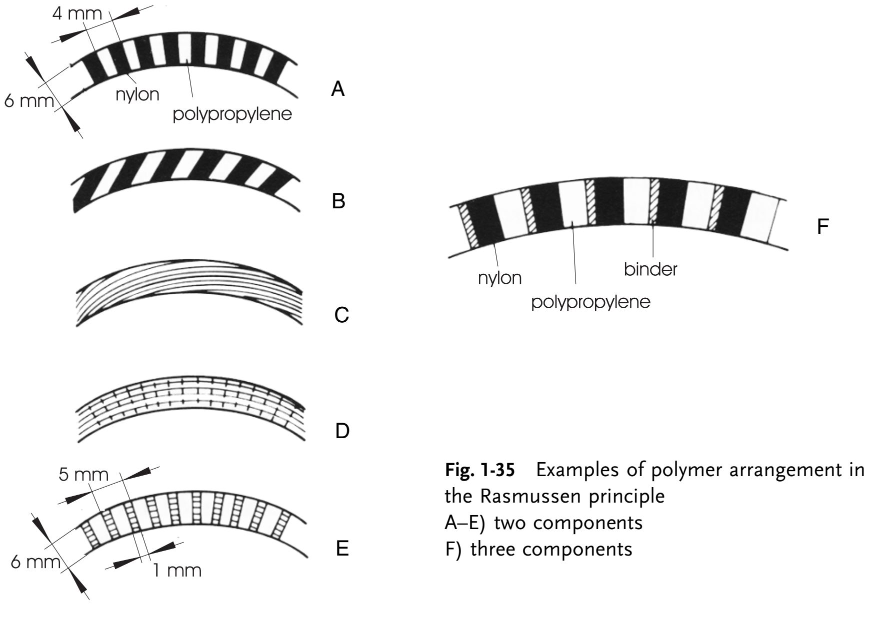


Fig. 1-35 Examples of polymer arrangement in the Rasmussen principle
A–E) two components
F) three components

The possibilities extrusion offers are listed in Table 1-11. They are still rather theoretical because the methods for the production of web from film are still scarcely used on a commercial scale. However, wherever their physical properties render them useful, the fine networks are processed. This technology is used more frequently for a simplified (shortened) yarn-making process today. In prac-

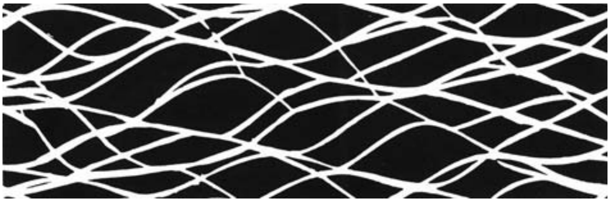


Fig. 1-36 Fibre network

Table 1-11 Various methods of film extrusion for web production

	Type of polymer	*Web formation*		*Web bonding*	*Nonwoven finishing*
Process parameter	type of polymer	extrusion fibre thickness crimp fibre cross-section	laying web organisation	thermal chemical mechanical	dyeing printing finishing
Styling possibilities	physical- and physico-chemical properties		volume handle appearance	handle appearance mechanical properties	volume handle appearance special properties

tice, the individual fibre thickness ranges from 3 to 10 dtex. One can also produce finer fibres of i.e. 1 to 3 dtex.

The characteristics of the most important polyolefine fibres are compiled in Table 1-12. They also apply to the film fibres outlined above. The most interesting figures are given in Table 1-12, the low melting points and the values for the density. In this context, it must be noted that shrinkage occurs before melting, which appears when work is done at temperatures close to the already low melting point of the polyolefine fibres.

Other characteristics of the fibres important for nonwoven bonded fabrics are that

- the customary polyolefine fibres cannot be dyed with the usual procedure. That is why they are dyed before spinning. Chemically modified fibres are also available, which, though they are dyeable, are expensive as well
- the light resistance of commonly used polyolefines is not sufficient. However, this circumstance can be ameliorated fairly easily and at rather low cost. In most cases the spun-dyed fibres are light-resistant enough for the purpose in question

Table 1-12 Characteristic properties of the most important polyolefine fibres

		Polyethylene	***Polypropylene***
Maximum tensile strength dry	cN/tex	50–72	40–94
Relative wet strength	%	95–100	100
Maximum elongation	%	35–20	22–15
Shrinkage (95 °C, H20)	%	5–10	0–5
Melting point	°C	100–120	164–170
Density	g/cm^3	0.92–0.96	0.90–0.91

- if stretched and set under pressure even in a cold state, the fibres "float" irreversibly
- thus, their recovery is insufficient for many purposes. The circumstance that there is irreversible creep can sometimes be offset by choosing a specific type of construction for the fabrics made from these fibres, e.g. by increasing density to an appropriate high level in the raw state for needled floor coverings
- the fibres do not absorb any moisture, which makes them fit for outdoor use or use on water

As polyolefine fibres are relatively inexpensive compared to other synthetic fibres, the producer of nonwoven bonded fabrics cannot ignore them. There are in fact special fields of application, where the mentioned fibre properties are not a liability but can even be employed in a useful way. It is always advisable to consider mixing polyolefine fibres with other fibres, e.g. as intermediate layers. Something that can lead to complications, though, is the use of polyolefins as a simple substitute for other fibres, without taking into account their special properties.

Polyacrylonitrile fibres

The raw material polyacrylonitrile results from the polymerisation of acrylonitrile, also known as vinylcyanide. Polyacrylonitrile is made into fibres by wet or more often dry spinning; it deviates from the previously discussed synthetic chemical fibres which are produced in the melt spinning process. This is necessary, as polyacrylonitrile cannot be melted without being decomposed.

As Fig. 1-37 shows in a diagram, the white polyacrylonitrile powder dissolved in dimethyl formamide (DMF) or in similar solvents is wet-spun in a water bath containing only few additives.

During the dry spinning process the spinning solution is forced through nozzle holes into a vertical 5 m to 6 m high chimney, where hot air flows towards the filaments, causing most of the solvent to evaporate. Most wet- or dry-spun polyacrylonitrile filaments are then made into spun fibre (Fig. 1-38). Pure polyacrylonitrile cannot be dyed using traditional methods. Therefore approximately 10% of a fibre forming chemical (copolymer) is included by polymerisation in the polyacrylonitrile which is to be spun, a chemical that ensures good and easy dyeing with basic

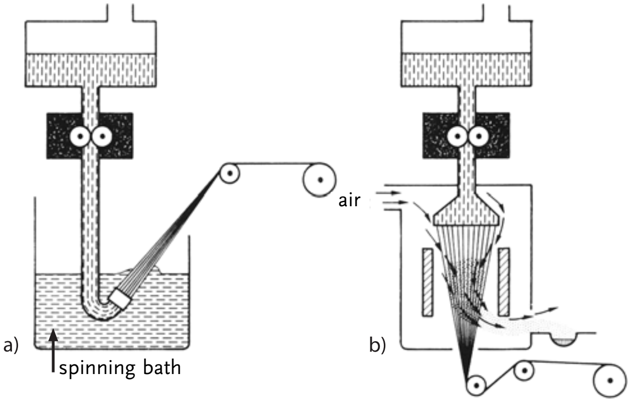


Fig. 1-37 a) Wet and b) dry spinning process for the manufacture of polyacrylonitrile fibres

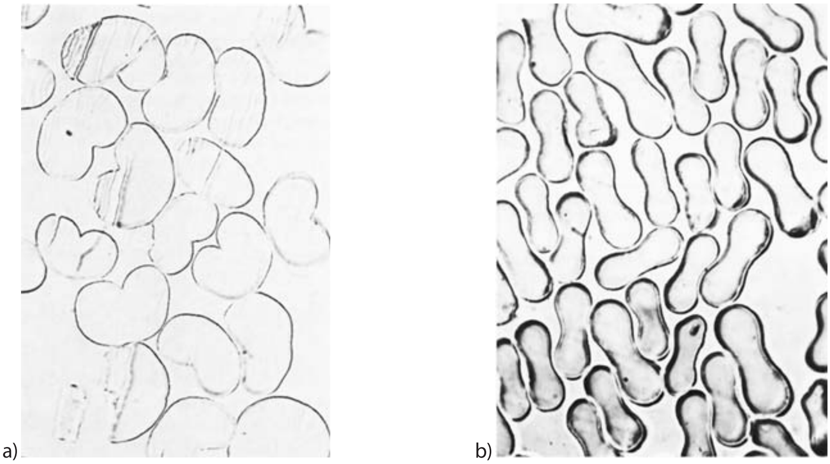


Fig. 1-38 Cross-sections of polyacrylonitrile fibres: a) wet-spun, b) dry-spun

dyestuffs. The maximum amount of copolymer allowed is 15% if the name polyacrylonitrile is still to be applied. As explained in the section about bicomponent fibres, this additive also accounts for the good crimp properties of the polyacrylonitrile fibres. These fibres are nearly exclusively processed into spun fibre and give yarn and fabric a remarkable volume.

The characteristic properties of polyacrylonitrile fibres are listed in Table 1-13, where no differentiation of interest for manufacturers of nonwoven bonded fabrics between wet- and dry-spun fibres has to be made.