

Microfibres — An overview

Sanrat Mukhopadhyay¹

Department of Textile Technology, Indian Institute of Technology, New Delhi, 110 016, India

Received 6 June 2001; revised received and accepted 18 December 2001

A microfibre can be polyester, nylon, acrylic, rayon or lyocell, spun in such a way so that the filaments are finer than 1.0 denier. The article is an overview on some of the important developments that have taken place in the field of microfibres. The interesting applications of microfibres in various fields have introduced leading fibre manufacturers like DuPont, BASF, Hoechst, Trevira, Teijin, Lenzing and Wellman make their own brands of microfibres. Nevertheless, high cost, lack of experimentation, less research in the field of new machinery and want of expertise to handle these fibres have hindered the growth of the microfibre market. These areas need particular attention if the potential of this fibre is required to be tapped.

Keywords: Artificial leather, Bi-component fibres, Microfibres, Texturing

1 Introduction

One of the most significant developments in recent years has been the technology to extrude extremely fine filaments while maintaining strength, uniformity and processing characteristics expected by textile manufacturers and consumers. These microfibres are even finer than luxury natural fibres, such as silk. This comparison, coupled with their exceptional performance, has led some in the industry to refer to microfibres as “supernatural”.

Up to now, there is no generally accepted definition for microfibres. But normally the term is linked to the fibre diameter and/or weight/ length of filament in dtex or denier and not with any properties of the fibre. Fibres in the 0.1 - 1.0 dtex range are termed as microfibres and the fibres finer than 0.1 dtex as ultra-microfibres. Any fibre finer than silk can be termed as a microfibre.

Dr Miyoshi Okamoto, a chemist in the Toray Industries textile research laboratory, introduced the first microfibre in the mid-sixties. Initially, the microfibre had various limitations, which were overcome by the success of *imitation leather*. In many product lines, it is the luxurious feel and look of the fabrics that makes microfibres so special. In others, it is this unique physical and mechanical performance. Today, the microfibres have taken a place of their own by virtue of their unique properties and end uses.

¹Phone: 0091-011-6596646;
E-mail: sm_iitd@yahoo.com

2 Preparation of Microfibres

2.1 Continuous Filament Type

There are following two ways to produce microfibres of the continuous filament type:

2.1.1 Direct Spinning

In the direct extrusion process, the fineness of the fibre is restricted to 0.1 dtex because of the fibres sticking together. Methods of blowing apart the fibres extruded from the molten polymer on a conveyor belt have achieved success in the spunbonded nonwoven industry. Direct spinning of POY with high number of filaments, such as 250 dtex / 196f (implies overall count of 250 dtex with 196 filaments), which would result (say) in a drawn and textured yarn of 150 dtex/196f. The yarn has to be interlaced in spinning to give reasonable processability in texturing. Though the direct spinning process suffers from setbacks like fibre breakdown, variation in filament thickness and spinneret clogging, it is still in practice.

Short irregular fine fibres can be made by melt blowing or by a centrifugal spinning technique. All these techniques produce fibres which are very irregular, vary in denier and are not continuous for very long lengths. Some of the recent techniques are described below:

2.1.1.1 The Moriki Technique¹

The Moriki technique is not suitable for extruding large numbers (e.g. 1000-10,000) of multicomponent fibres from each spinneret as is necessary for

economical production of staple fibres via melt spinning. By using tubes to feed each core stream, the number of tubes is limited by the smallest practical size of tubing available, thereby requiring considerable space. Additionally, if very fine tubes are employed, it would be expensive to assemble them into their retainer plate. In cleaning the spin pack parts (typically every week), it would be hard to avoid damaging the tubes. Since the tubes have an inside diameter with a very high ratio of length-to-diameter (i.e. L/D), it would be hard to clean the inside of each tube. The tube design would certainly make the parts too expensive to be discarded and replaced instead of being cleaned. When cleaned and undamaged, however, the Moriki device can manufacture very uniform high-quality fibres.

2.1.1.2 The Kessler Technique

The Kessler apparatus, on the other hand, is more rugged. This apparatus employs machined inserts, permitting a number of polymer side streams to be placed about the periphery of a central stream. Also, by using short tubes, some side streams can be injected into the center of the main stream, giving a result which would be similar to that obtained by Moriki. Again, the size limitations on the machined insert and the smallest practical side tubes make the Kessler apparatus suitable for spinning a limited number of composite filaments per spinneret. Proper cleaning and inspection of the side stream tubes requires removing them from their support plate, a very tedious process for a spinneret with one thousand or more inserts. The Kessler technique may, however, be quite suitable for making continuous filament yarn, as described above for Moriki.

2.1.2 Indirect Spinning

Another popular way where most of the innovations are taking place is bicomponent spinning of yarns, where each filament splits into a multitude of smaller filaments after a chemical treatment during the finishing of the fabric. In this spinning process, the island in a sea type, the split type and the multi-layer type are the major varieties.

In the island-in-sea process, one polymer is fed in individual streams inside the sea of another polymer. The spun filaments have a total denier of 2 - 5 dpf (12 - 20 microns) after drawing. The sea polymer is dissolved away generally after the fibres are knit or woven into fabric to leave small submicron island filaments on the surface of the fabric. 24 and 32

islands-in-the-sea fibres have been around for a number of years and are used to make products such as ultra-suede and artificial leather. Now commercial operation with 64 islands for both staple and filament yarns is in practice (Fig. 1). Typical polymer ratios are 20% sea and 80% islands. When the island polymer is greater than 65% of the total filament mass, the island filaments become square in shape due to the packing density.

The microfibre fineness can be defined as

$$D = dl \times (R/100) / N$$

where dl is the extruded fibre fineness; R , the island content; and N , the number of islands.

In split spinning,² there are various methods. One method includes the steps of forming fibrillizable or splittable multicomponent conjugate fibres into a fibrous structure and then treating the fibrous structure with an aqueous emulsion of benzyl alcohol or phenyl ethyl alcohol to split the composite fibres. A second method has the steps of forming splittable conjugate filaments into a fibrous structure and then splitting the conjugate fibres of the fibrous structure by flexing or mechanically working the fibres in the dry state or in the presence of a hot aqueous solution. In the third method, the conjugate fibres are hydraulically or mechanically needled to fracture and separate the cross-sections of conjugate fibres, forming fine denier split fibres. Kanebo, Teijin and Toray have adopted the principle of splitting to



Fig. 1—Microfibre prepared through the indirect spinning process having 64 islands in sea (Source: www.hillsinc.net)

produce microfibrils. The cross-sections of different spinnerets used by them are shown in Fig. 2.

The multi-layer type spinning³ utilizes static mixtures. Kanebo, Kuraray and Toray have done experiments with this process. Kuraray was the first to come up with a successful version. A conjugate fibre is spun from polyester and nylon 6, which is then converted into 0.2-0.3 denier filaments.

An U S Patent⁴ discusses the splitting and multi-layer type spinning and reports the development of a composite fibre consisting of two components, for example, a polyamide and a polyester. Then the two components of the multi-segment fibre can be separated into a plurality of microfibrils by chemical and physical treatments. The fibre developed by this method has low loss of weight in a chemical treatment and can easily be separated into outer and inner components. After separation, the composite fibre gives excellent performance.

Both the direct and indirect ways are being practiced today. The first one is a more economical method because of a much lower investment cost for such yarns. The latter one allows the production of very specialized yarns with interesting cross-sections.

2.2 Random (staple) Type

This kind of fibres are mainly produced by the underlying methods, which have been discussed at length by Nakajima⁵

- Melt blowing or jet spinning
- Flash spinning
- Polymer-blend spinning
- Centrifugal spinning
- Fibrillation or violent flexing

3 Various Microfibrils

Microfibrils have almost become synonymous with polyester and nylon. Trevira Finesse, Fortrel Microspun, DuPont Micromattique and Shingosen⁶ are all trade names for various polyester microfibrils while Supplex Microfibre, Tactel Micro and Silky Touch are some of the trade names for nylon microfibrils

Though the majority of the experiments and

developments have taken place with polyester and nylon, there have been interesting developments with other fibres too.

3.1 Acrylic Microfibre

Montefibre has been one of the first synthetic fibre producers active in developing and producing acrylic microfibrils. A new polymer and a new continuous spinning process have been developed to produce acrylic microfibrils Myoliss and Leacril Micro with filament counts of 0.9-0.8 and 0.6 dtex without losing spinning machine capacity and quality fibre consistency compared to the high filament counts production. Myoliss for the worsted system and Leacril Micro for the cotton system, both ring and open end, have an excellent fibre-to-yarn processability, allowing the production of fabrics highly innovative for soft touch, aesthetics and for wear comfort to satisfy the needs of a more sophisticated market. Montefibre is pursuing the development in this field with new types of Leacril Micro with improved fibre-to-yarn processability and with new performances on final fabrics.

3.2 Polypropylene Microfibre

An U S Patent⁷ discusses a multi-layered absorbent, protective nonwoven web which has one or more center layers of melt-blown polypropylene microfibrils which are naturally hydrophobic. The center layers are sandwiched between one or more melt-blown surface layers on each side. The surface layers are composed of melt-blown polypropylene microfibrils which have been rendered hydrophilic by addition of a nonionic surfactant during formation of the surface layer microfibrils.

3.3 Cellulose Microfibre

Fibrous absorbent webs having a low density (about 0.01 - 0.15 g/cm³) and comprising at least about 50% cellulose microfibrils having a diameter of from about 0.01 μ to about 15 μ have been reported in an U S Patent⁸.

4 Developments in Microfibre Manufacturing

4.1 Changing the Cross-section without Changing the Spinneret

Fibres of virtually any cross-sectional geometry are formed by melt-spinning fibre-forming polymers though specially designed spinnerets. Thus, to obtain fibres of a specific cross-sectional geometry, a corresponding spinneret orifice of specific geometric design is typically needed. An interesting exception to this

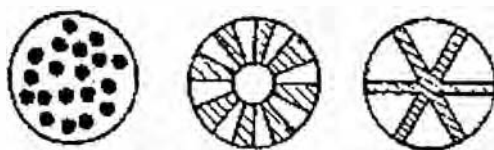


Fig. 2—Cross-sections of different spinnerets

has been reported in a patent. According to the patent⁹, at least two polymers can be co-melt-spun through an orifice of fixed geometry so as to achieve a bicomponent fibre having a desired cross-section. In order to change to a bicomponent fibre having a cross-section, which is different, at least one of following is to be changed: (i) the differential relative viscosity between the first and second polymers, (ii) the relative proportions of the first and/or second polymers, and (iii) the cross-sectional bicomponent distribution of the first and second polymers.

A wide variety of bicomponent fibres having different cross-sectional geometries may be produced without changing the fixed geometry orifice through which the polymers are co-melt-spun. Thus, the bicomponent fibre cross-sections may be "engineered" to suit a variety of needs without necessarily shutting down production fibre-spinning equipment in order to change spinnerets.

4.2 New Ways to make Nonwovens from Cellulosic Microfibres

The institute TITK-Rudolstadt succeeded in spinning cellulosic microfibres by specific mechanical shear deformation of cellulose/NMMO solutions. The presence of viscous desolvation media consisting of solutions of fibre-forming polymers in DMF or DMAc is a necessary condition. Cellulosic microfibre nonwovens can be manufactured by simple filtration from the microfibre dispersions. It is also feasible to spin the microfibre dispersions to matrix-fibril-fibres, whereby the cellulosic microfibres are positioned longitudinally to the fibre axis. These matrix-fibril-fibres can be processed to microfibre nonwovens by traditional textile methods.

4.3 Radial Quenching System

With the Ems-Inventa radial outflow quenching system, the loss in capacity was avoided. A suitable modification of the standard system leads to the most economic and optimal production conditions for the processing of microfibres. Also in the microfibre range, the advantageous quality figures, in comparison with other cooling devices, are achieved with the use of radial quenching device.

4.4 A New Self-suction Cooling Device

Akzo Nobel Faser AG, Germany¹⁰, have developed a new process for the spinning of microfibre POY yarns. The process utilizes a self-suction device to cool the filaments after melt extrusion. Details are provided of the work carried out on a multiple

position pilot unit to assess its potential for spinning filaments from 0.4 dtex to 1 dtex including the design of the cooling unit, yarn path, application of spin finish, spinneret design and the properties of the yarns obtained. It was found that the process offered excellent spinning reliability.

5 Texturing Machines for Microfibres

With the production of microfibres, the demand to texture such fibres became quickly a reality. But to the consternation of the texturing industry, microfilament yarn seemed to be very difficult to texture. Broken filaments and the inability to utilize the yarns on high speed looms were the major setback. ARCT (today ICBT) of France introduced years ago, in a Textured Yarn Association of America (TYAA) meeting in Myrtle Beach test results of an improved machine design. The trick was to have a basically single curved texturing zone and cooling zone without any major deflections. This concept was later picked up and further refined by nearly every other texturing machine producer. Now interlacing the finished textured micro yarn is an accepted standard, allowing much improved weaving, warping and knitting speeds.

Microfibre is more heat sensitive and hence requires precautions like straight and short yarn path in texturing zone, specially designed low-friction ceramic guide surfaces and specially designed polyurethane friction disks for an even twist insertion. The fibre should be processed at 20 - 30% lower texturing speed, no second heater treatment is necessary because of the fibre's low crimp modulus and micro-coning oil to cater to the special needs of the wicking action of microfibre.

Here is an example for machine set-up for microfibre made from POY:

Draw ratio	:1.59
1st Heater temp.	:180 ° C
Friction disks	:One ceramic entry disk. One ceramic exit disk
D/Y (Disc-to-yarn) ratio	:1.95:1

6 Microfibre Dyeing Developments

Burkinshaw *et al*¹¹, reported the use of 13 acid dyes on conventional and microfibre knitted nylon 6,6 fabrics with four different dyeing methods. The dyes exhibited a faster rate of uptake, higher extent and rate of dye desorption, lower wash fastness and lower colour strength on microfabric than on a conventional

one. These findings can be attributed to the greater surface area of the microfibrils.

The effect of supercritical dyeing conditions on the morphology of polyester microfibrils was studied by Drews and Jordan¹². They have shown that supercritical dyeing has no adverse effect on the fibre structure.

Nakamura *et al.*¹³ have reported the dyeing properties of polyester ultrafine fibres (0.07 denier) with disperse dyes. A good comparison is made in by them regarding sorption and diffusion behaviour of disperse dyes on 0.07 denier polyester fibres made by the sea-island type spinning and the microfibrils made by the conventional melt-spinning process.

Savarino¹⁴ reported that the dye uptake by fabric made of microfibre versus dye concentration in the liquor bath clearly show the higher dye uptake by the microfibrils than normal fibre.

Dieval *et al.*¹⁵ studied the polyester microfibre and fibre structure by critical dissolution time. The results showed that microfibre has a structure allowing good diffusion of the dye and showed that independent of the fineness, structural differences do exist between classic polyester and microfibrils.

7 Finishing on Microfibrils

Various finishes have been applied on microfibrils. Some of the finishes, popular in the industry, are:

Charisma—dress weight with suede-like finish
 Ultima—water-repellent finish
 Moonstruck—soft sueded finish, silk-like
 Micromist—brushed finish
 Regal—dry hand
 Silkmore—sandwashed silk finish
 Stanza—water-repellent microtwill
 Vanessa—reversible fabric for rainwear

8 Microfibre Blends

8.1 Polyester and Nylon

Polyester microfibre as the sole constituent of a cloth will wear and shed fibre with use. So it is best utilized (as it is in Googalies)¹⁶ in combination with nylon. When nylon is combined with the polyester microfibre in just the right combination, a cloth results with the advantages of both synthetics. Too much nylon will result in a cloth that will scratch fine or delicate surfaces like coated optics or fine wood or paint finishes. Too little nylon will result in a cloth that will not last or clean rough surfaces like guitar strings without rapid deterioration. It is this perfect

combination of polyester and nylon microfibre that make Googalies the wonder it is.

Another similar product¹⁷ that has become popular in China is a combination of 80% polyester microfibre and 20% polyamide microfibre. It is environment friendly, free of odors and chemicals, non-allergenic, very soft and harmless to the skin on surface. With the high-density weaving, it has excellent absorption capacity. The fabrics made of this microfibre are available in knitted, terry towel, suede, woven and nonwoven forms.

8.2 Synthetic and Cotton

A U S Patent¹⁸ reports a wiper comprising a melt-blown web having a mixture of synthetic and cotton fibres. The combination provides highly improved wiping properties as well as strength and absorbency for many industrial applications requiring wiping of oily and/or aqueous materials. The wipers are formed by a conventional melt-blowing process involving the extrusion of a thermoplastic polymer as filaments into an air stream which draws and attenuates the filaments into fine fibres having an average diameter of up to about 10 μ . The staple fibre mixture of synthetic and cotton fibres may be added to the air stream, and the turbulence produced where the air streams meet results in uniform integration of the staple fibre mixture into the melt-blown web. There is a reference¹⁹ of using synthetic microfibrils in association with other natural fibres like cotton, wool, and silk.

9 Various Uses of Microfibrils

Microfibrils have been put to various uses. It is not possible to list all of them. Some of the most important and interesting uses are underlined below.

9.1 Industrial

A novel product, disclosed in a patent²⁰, uses microfibrils for cleaning up oil spills. The product comprises ultra-fine polymeric fibres which are produced from various polymeric materials by mixing with thermoplastic poly(vinyl alcohol) and extruding the mixture through a die followed by further orientation. The poly(vinyl alcohol) is extracted to yield liberated ultra-fine polymeric fibres. The fibres are ultimately processed into said product, such as a mat, which is placed directly on the oil spill to absorb the oil.

Low-cost wiper material for industrial and other applications having improved water and oil wiping

properties has been reported in an U S Patent²¹. A base material of melt-blown synthetic, thermoplastic microfibres is treated with a wetting agent and may be pattern bonded in a configuration to provide strength and abrasion resistance properties while promoting high absorbency for both water and oil. The wiper displays a remarkable and unexpected ability to wipe surfaces clean of both oil and water residues without streaking. It may be produced in a continuous process at a low cost, consistent with the convenience of single use disposability.

Another U S Patent²² describes a non-woven material useful for disposable wipers and the like which comprises a layer of melt-blown polymeric microfibres inter-mixed with fibres of absorbent material and absorbent or super-absorbent particles. Such material can readily absorb fluids, including oil, and can subsequently be squeezed out readily. The material also has an integral strength and a substantially lint-free wiping surface.

An air pollution control process²³ employing an improved rotatable collector, which by its position becomes a filtering and adsorbing station and a combustion and desorbing station, and an oxidizer are utilized in an apparatus and process for removing airborne particulate materials and organic vapours from an air stream. The rotatable collector comprises an assembly of alternate layers of refractory microfibres, metal screens, and a thin layer of adsorbent carbon.

Waterproof, multilayered nonwoven fabric of reduced weight having good vapour permeability and the method for its production has been described by Corovin, GmbH. The fabric comprises at least one layer of coarse, melt-spun, thermoplastic filaments and at least one layer of fine, melt-blown thermoplastic microfibres. The layers are thermally bonded together at intermittent points and, while being heated, are subjected to a force in at least one direction without tearing. The coarse filaments are elongated in the direction of force and the fine microfibres are straightened in the direction of force, in the absence of drawing, to form a denser array of the microfibres having a lesser thickness within the resulting fabric.

A U S Patent²⁴ provides a fibrous web, which exhibits high thermal resistance per unit thickness. This web incorporates microfibres (generally less than 10 μm diameter), but only as one component fibre in the web. In addition, a web includes bulking fibres, i.e. crimped, generally larger-diameter fibres, which

are randomly and thoroughly intermixed and entangled with the microfibres and account for at least 10% by weight of the fibres in the web. The crimped bulking fibres function as separators within the web, separating the microfibres to produce a lofty resilient web capable of filling a much larger volume than a conventional microfibre web. This web can be used as excellent thermal insulator.

9.2 Medical

A patent²⁵ describes a fabric sheet, a curable resin coated onto the fabric sheet and a plurality of microfibre fillers dispersed into the resin. The incorporation of microfibre fillers into the casting materials adds substantially to the strength of the cured casting material, particularly when the fabric used therein is a non-fibreglass fabric

9.3 Apparel Use

Evolon, launched by Freudenberg Nonwovens, is made from continuous microfibres. The Evolon process has filament spinning and web formation after which high pressure water jets split the continuous filaments into 0.05-0.2 dtex microfibres. Fabrics intended for garments from Evolon have outstanding drape and handle, are comfortable to wear, can be given hydrophobic or hydrophilic treatments and can be laundered easily.

Kuraray²⁶, the market leader in the development of man-made leather, has introduced the new Amaretta JP man-made suede. The new product satisfies both aesthetic and physical properties criteria. The product is based on a polyester microfibre and a microporous polyurethane resin.

Unitika Ltd has developed a stretchable synthetic suede, Silseim, for furniture applications. Made from polyester microfibres (82%) and polyurethane resin (18%), the product offers effects similar to leather.

Kanebo Gohsen Ltd has developed a fabric called Beledano using Belima SX microfibres. Belima SX is 0.05 denier compared to the 0.1 denier of Belima X polyester/nylon ultrafine microfibre used to produce suede-type fabrics. Belima SX is produced by spinning a bicomponent fibre which is then split and divided in a special finishing process. Beledano is currently being marketed for apparel applications, such as coats and jackets, as well as for interiors.

Various microfibre jackets are now in use. For example, a website²⁷ advertises for a 100% polyester sueded microfibre body with water repellent finish,

convertible collar with button-tab closure, full-zip front, slash front pockets with snap closure, locker loop, inside pen pocket, rib knit cuffs and waistband, polyester/cotton lined body. A reversible golf length jacket having 100% polyester sueded microfibre body with water repellent finish is also advertized.

9.4 Household Applications

A super absorbent drying towel²⁸ uses microfibre that eliminates the need to use any soap or detergent as claimed by the producer. The microfibres with their enhanced surface area grab the grease and dirt. It also gives much better cleaning results in less time.

Another company²⁹ advertises for super-microfibre fabrics that consist of 0.2-0.3 denier synthetic yarns such as polyester and nylon/polyester mixture. The surface of the microscopic fibres gently cleanses pores without irritating delicate skin. The water retention capacity is 2-3 times more than that of normal cotton fabrics. The fabric has been successfully used for wiping clothes for cleaning kitchen & utensils/ household furnishings/ cars/ mirrors/windows, cleaning of eye glasses, as hair towels/ bath towels/ face cloths/ exfoliating towels/ sports towels/ mittens.

9.5 Sports

A hand sewn football³⁰ is advertized in the net with the constituents as high solid polyurethane, 4-layer microfibre textile, 1 layer of back Neoprene French foam, Natural latex with butyl valve.

9.6 Miscellaneous

Improved absorbent products are reported in a patent³¹ based on microfibre technology. The absorbent products comprise pressure-sensitive microfibres that provide good liquid transport properties and resiliency and mask the odours associated with bodily fluids. The microfibres of less than 1 dtex are formed using molten spray technology and are used to form coatings on the substrate of 0.002 - 0.084 g/m². They are sprayed onto the absorbent core using a spray nozzle or a melt-blown technique. They can be used in sanitary napkins, incontinence garments and disposable diapers using less expensive techniques.

Sterling Fibers,³² along with Glenoit Corporation, developed microfibre pile utilizing MicroSupreme® high tech acrylic. In construction of pile fabrics, a sliver is created and then knit into a backing and eventually sheared to the specific pile height desired. Jacquard designs may be knit into the fabric, resulting

in a very precise, crisp, clean and long-lasting pattern. These fabrics are known today as MicroBerber™, MicroGlenaura™, MicroFabric™, MicroLana™ and GlenPile®. These micro pile fabrics are used in high tech and fashion outdoor lines, branded coat, sportswear, accessories (hats, gloves, scarves), footwear, robes and loungewear as well as in home textiles and upholstery. New lighter weight fabrics are ending up in spring/summer applications such as golf.

A patent³³ describes composite sheets made of ultrafine sheath-core composite fibres. The composite fibres have a fineness in the range of 0.0001-0.5 denier and a core/sheath weight ratio in the range of 10/90-70/30. When the composite fibres are combined with an elastic material such as polyurethane, suede-like artificial leathers having excellent softness, touch, feel and colour can be obtained.

16 Limitations and Precautions

The most important limitation of microfibres is their heat sensitivity. Because the fibre strands are so fine, heat penetrates more quickly than with thicker conventional fibres. As a result, the microfibres are more heat sensitive and scorch or glaze if too much heat is applied or if it is applied for too long a period. Generally, the microfibres are wrinkle resistant, but if pressing is needed at home or by drycleaners, care should be taken to use lower temperatures. Static may develop in fabrics from synthetic microfibres, especially during dry winter when heating systems are turned on and the humidity is low. Fabric softeners in the rinse cycle of the washing machine may lessen the problem. As with all fine garments, rough or jagged jewelry should be avoided. It can cause pulls, snags or general abrasion to garments. Although microfibres in a yarn are strong, the individual fibres are extremely fine and could abrade easily.

11 Conclusion

Microfibre holds a lot of promise for the future. The much friendlier properties of microfibres, as compared to those of other man-made fibres, have been able to revitalise the man-made fibre market. However, extensive research is needed to produce these fibres at a much lower cost.

References

- 1 Moriki Y & Ogasawara O, *U S Pat* 4,445, 833 (to Toray Industries Inc, Tokyo), 1 May 1984.
- 2 Richard D, Anthony P, Jason E & Stokes A, *U S Pat* 5759926 (to Kimberly-Clark Worldwide Inc, Neenah, WI), 2 June 1998.

- 3 Nakajima T, *Advanced Fibre Spinning Technology* (Woodhead Publishing Limited, Cambridge, England), 1994, 199.
- 4 Yeun H, Jong L & Hak M, *U S Pat* 4460649 (to Kolon Industries Inc, Seoul, Republic of Korea), 17 July 1984.
- 5 Nakajima T, *Advanced Fibre Spinning Technology* (Woodhead Publishing Limited, Cambridge, England), 1994, 200.
- 6 <http://ohioline.ag.ohio-st>.
- 7 Ronald F & Monica C, *U S Pat* 4753843 (to Kimberly-Clark Corporation, Neenah, WI), 28 June 1988.
- 8 Allen D, David W & Paul T, *U S Pat* 4468428 (to The Procter & Gamble Company, Cincinnati), 28 Aug 1984.
- 9 Charles F, Otto M, Diane R Hoyt, Matthew B & John A, *U S Pat* 5948528 (to BASF Corporation, Mt Olive, N J), 7 September 1999.
- 10 Peschke W, Schilo D & Weber M, *Chem Fibers Int*, (1997) 62.
- 11 Burkinshaw S M, Maseka K D & Cox S D, *Dyes Pigm*, 30 (1996) 105.
- 12 Drews M & Jordan C, *Text Chem Color*, 30 (1998) 13.
- 13 Nakamura T, Rarna R & Kamiishi Y, *Text Res J*, 70 (2000) 961.
- 14 Savarino P, *Dyes Pigm*, 42 (1999) 143.
- 15 Dieval F, Mathieu D, Viallier P & Durand B, *Text Res J*, 71 (2001) 239.
- 16 <http://www.googalies.com/microfsa.html>.
- 17 <http://www.chinamarket.com.cn/E/Showdetail/32101.html>.
- 18 Gary H & Harry W, *U S Pat* 4426417 (to Kimberly-Clark Corporation, Neenah, WI), 17 January 1984.
- 19 <http://ohioline.ag.ohio-st>
- 20 Lloyd M, Robert J & Thomas A, *U S Pat* 5120598 (Air Products and Chemicals, Inc, Allentown, PA), 9 June 1992.
- 21 Gary H, *U S Pat* 4307143 (to Kimberly-Clark Corporation, Neenah, WI), 22 December 1981.
- 22 Dennis G, *U S Pat* 4784892 (to Kimberly-Clark Corporation, Neenah, WI), 15 November 1988.
- 23 George D, *U S Pat* 4415342 (to Minnesota Mining and Manufacturing Company, St Paul, MN), 15 November 1983.
- 24 Edward R, *U S Pat* 4118531 (to Minnesota Mining and Manufacturing Company, St Paul, MN), 3 October 1978.
- 25 Matthew T, *U S Pat* 5474522 (to Minnesota Mining and Manufacturing Company, St Paul, MN), 12 December 1995.
- 26 *High Performance Textiles*, 10 (2000) 12.
- 27 <http://www.vectv.com/jacket.html>.
- 28 <http://www.kitchen-classics.com/mysticma.html>.
- 29 <http://www.fcc.co.jp/tomen-ht/super.html>.
- 30 <http://www.sportsmnore.com/soccer/balls/patrick.asp>.
- 31 Korpman R, *U S Pat* 5885681 (to MCNEIL-PPC, INC), 23 March 1999.
- 32 <http://www.sterlingfibres.com/pile.html>.
- 33 Okamoto M, Iijima H & Miyoshi A, *U S Pat* 4557972 (to Toray Industries, Inc, Tokyo, Japan), 10 December 1985.