Engineering and applications of ultra fine denier fibres

R.Ramachandran & P.Kanakaraj, Lecturers, Department of Fashion Technology,
PSG College of Technology, Coimbatore, India.

1. Introduction

Fine diameter fibers have always been of interest in special purpose applications. The term microdenier, relates to synthetic fibers has been in general use in the textile industry for many years. Specifically, it has come to refer to synthetic fibers with denier per filament (dpf) of less than one; however, it is most often used for any fiber with a dpf between 0.5 and 1.5. Synthetic fiber spinning equipment and processes have improved rapidly since the early days, when fiber producers had to develop their own in-house equipment and process technology. By the late 90's it became economically viable to spin and process into fabric both filament and staple synthetic fibers with dpfs of less than one.

New growth opportunities are being discovered in the nonwovens field and fibres are engineered with specific performance characteristics for use in these nonwovens fabrics. ultra fine denier fibres have been specifically developed for these applications. ultra fine denier fibres refer to the fibres with the denier range between 0.5 to 0.05. The technology involves spinning and processing of multicomponent fibers in the range of 2 to 4 dpf, after which the fibers are split into smaller fibers with deniers of 0.5 or lower. Until recently, these technical advances, and consequently, those type of products have been very expensive and has found greatest acceptance in the Far East. Some of the techniques of manufacturing, structure and the method of fabric forming are highlighted in this paper.

2. Manufacturing process

In order to manufacture ultra fine denier fibres, the first stage is the manufacture of multi-component fibres which contains two or more type of fibres as their component.

Figure 1 illustrates splittable fibers as the world knows them today. The cross section is commonly referred to as "pie wedge" or "citrus," and the wedges are alternately made of nylon and polyester. It is common for such a fiber to have 16 segments. The conventional purpose of making a fiber like this is to form a card web of typically 3 denier per filament fibers, and to then pass the web under hydroentangling jets. The jets simultaneously split the fibers into individual wedges, and entangle the fibers to give the fabric strength and integrity. As a result, the fabric contains the fibers less than 0.2 denier per filament, but most of the throughput and processing advantages of a 3 denier fiber are maintained.

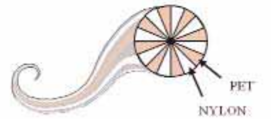

Fig.1: Standard pie wedge.

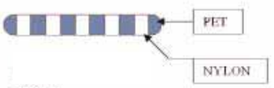

Fig.2: Segmented ribbon.

Fig.3: Segmented cross and tripped trilobal.

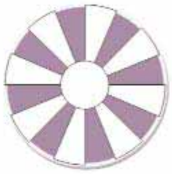

Fig.4: Hollow pie wedge.

Fig.5: Conjugate.

The most important thing a splittable fiber should do is to split. To ensure splitting, the process should start with dissimilar polymers. Even by choosing polymers with low mutual affinity, the fiber's cross section can have an impact on how easily the fiber will split. The cross section that is most readily splittable is a segmented ribbon, such as that shown in figure 2. One problem with such fibers is that, before they split, they are difficult to card because of the anisotropic bending moment. After they split, they are difficult to card because of the very small fiber denier.

The cardability can be improved by switching to a segmented multi-lobal fiber, such as the cross and the trilobal cross sections shown in figure 3. The cardability comes at the cost of a reduction in the splittability. A further disadvantage of each of these non-round fibers is the relatively high cost of spinnerets capable of forming the shaped cross sections. But where there is high splittability is required, these are the cross sections to use.In most cases, though, if the polymers will allow splitting at all, it is more important to prevent splitting before or in carding. Round cross sections are best for this and the easiest round cross section to split is the hollow pie wedge shown in figure 4. It also requires relatively expensive spinnerets, but it is often a good cross section for polymer, that can be split only with some difficulty. The standard pie wedge (Figure 1) does not require special spinneret capillaries, but is the most difficult segmented cross section to split.

A final option is illustrated in figure 5, referred to as a conjugate fiber. This fiber structure is likely to split easily when the splitting forces, such as force from hydroentangling jets, are applied in parallel with the segment edges, but would split less easily under forces applied perpendicular to the segments.

2.1. Advantages of using Polyester and Nylon

The best reason to use nylon and polyester (PET) for these fibers is that the two polymers have sufficiently little adhesion to each other, so that the wedges will actually split apart in hydroentangling. They are also widely available, the PET is relatively inexpensive, and there is a wide body of knowledge about the fiber spinning characteristics of both polymers.

2.2. Problems associated with Nylon and Polyester

The nylon and polyester are not ideal for all uses. For example, in synthetic suedes, the fabric is often dyed, and as both nylon and the polyester must be dyed, two separate dyeing must be performed, with two different types of dyes. This metamerism can be more of a problem, as against the use of only one type of dye, whereas, the two types of dyes may appear as different shades under fluorescent, or daylight illumination.

Another problem is with on-shade fading. Since the two different dyes will fade at different rates in response to light, laundering, and abrasion, the hue (shade) of the fabric will shift as it fades. If 100% polyester fabrics were dyed with one type of dye, it would still fade, but even as it got lighter, each of the dyed fibers would still maintain the same shade as all the others.

It would be ideal to make the fiber entirely with polyester, however, PET and other polyesters or co polyesters have high adhesion to each other to be easily separated from a segmented fiber. Therefore, PET and nylon represent a viable option and compromise.

In filtration, the problem is not with dye shades, but with the chemical resistance of the polymers. When filtering corrosive fluids, polyester and nylon often are too susceptible to degradation or dissolution in the stream being filtered. In this case, it would be ideal to split apart a segmented fiber made entirely of polypropylene (PP) segments, but again we run into the problem of not being able to separate polypropylene from polyethylene. Polyethylene (PE) has most of the chemical resistance of polypropylene, but PP and PE do not readily split apart, either. In wipes, nylon and polyester do pretty well in most cases.

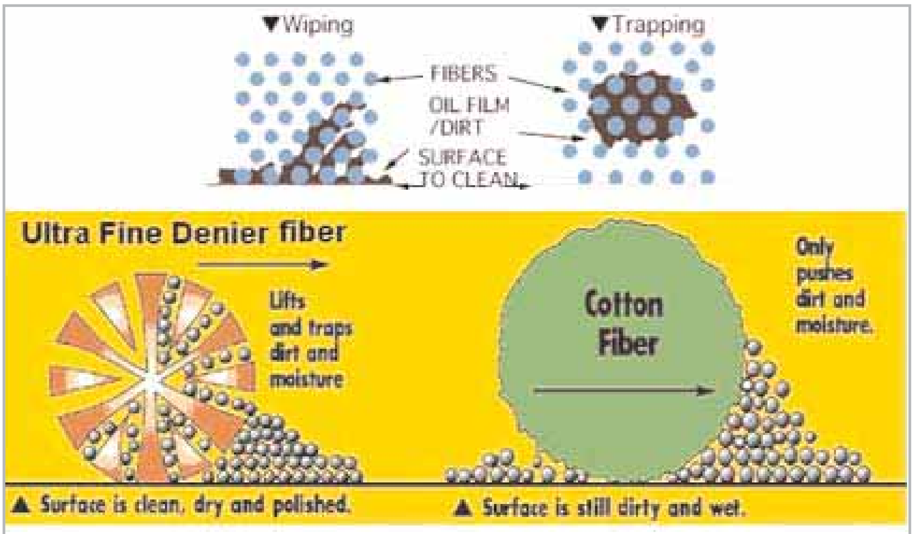

Fig. 6: Wiping and cleaning of ultra fine and cotton fibre cloths.

An even more powerful tool in achieving desired fiber performance characteristics is the way the properties of the two polymers are combined. In the case of a polyester and nylon pie wedge fiber, for instance, to minimize the fiber's material cost, the polyester content can be optimized, as shown in figure 7. This is also a way to minimize the negative effects of the nylon on the dye shade.

However, if the dyeability of nylon is preferred, or if the nylon's resiliency is valued highly, the nylon content can be optimized as shown in figure 8. In general, when one polymer carries all of the desired properties, the second polymer is used solely or primarily to achieve splitting and the proper cross section looks, as those shown in figures 6 and 7.

Even more productive, in the light of current experience, is the substitution of entirely different materials for the polyester and nylon. Though the process are limited to melt-spinnable polymers, there is still a wide array of properties available beyond those provided by "plain vanilla" PET, nylon, and polypropylene applications. Several new fibers that have resulted from efforts directed to modifying polymer content, polymer ratio, and cross section. These new fibers open the door to new functional possibilities in nonwovens made with these fibers.

2.3. All polyester splittable fiber

The first of these new fibers address the dye shade problem with nylon/polyester splittable fibers used in synthetic suede fabrics. In splittability PET and PLA split apart quite nicely and are much suitable for this type of fibres. This can be explained due to a fact that though PLA is a polyester, due to the ester formed in its polymerization, the monomer used is significantly different from those used in other commercially-available polyesters.

The most fundamental difference is that PLA does not contain an aromatic ring, therefore, its surface energy differs significantly from that of other polyesters, and allows the two to split apart. However, PLA is more like other polyesters, that it can be dyed with the same disperse dyes used to dye PET. As a result, whenever, the fabric fades, it will at least fade on-shade.

The disperse-dyeability of PLA also leads to the possibility of transfer printing of the synthetic suede, if a high-Tm PLA is used. PLA also is hydrophilic, so it improves over nylon in comfort for apparel applications, where moisture wicking is important.

Further, PLA is made from renewable resources (typically corn), so even though the PET comes from petroleum sources, the fabric at least has an ecologically-friendly component. Lastly, the use of PLA does not sacrifice any strength or resilience, previously supplied by the nylon, and may even provide some cost advantages.

2.4. All-Polyolefin splittable fiber

In the corrosive environments the all-polypropylene splittable fibers are used for filtration. Poly Methyl Pentene (PMP) and PP will split apart easily and the splittable fibres are made with these fibres. PMP is a true polyolefin, with chemical resistance essentially equivalent to that of PP, and even better than that of polyethylene.

And PMP's melt temperature is 240^{0}C, about 80^{0}C higher than that of PP. It has become possible that, at least before the segments split apart, the fiber could maintain its strength at temperatures above those where a PP fiber would begin to weaken. The main disadvantage of PMP application is higher cost, and for this reason, the application of these fibres are limited to certain extent.

2.5. Electret Fibres

The fibres made with PP and PAN (PolyAcryloNitrile) whose chemical resistance and splittability were almost as good as those of an all-PP splittable fiber. PP and PAN have little affinity for each other, and PAN also has very good chemical resistance. Its melt temperature is similar to that of PP.

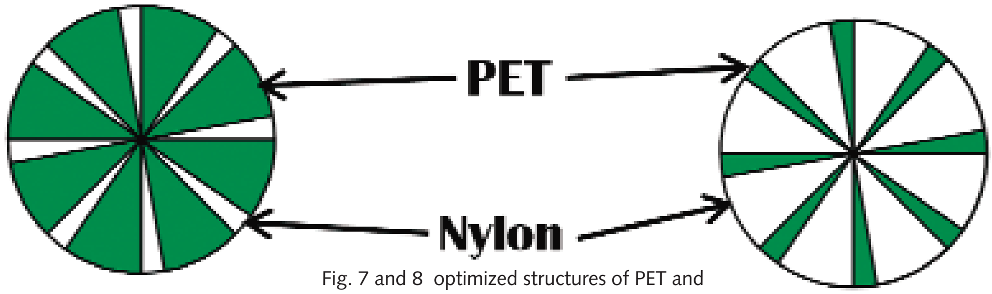

Fig. 7 and 8 optimized structures of PET and Nylon combination.

The cost of production of PAN is much more reasonable than that of PMP, so for applications, where the melt temperature and chemical resistance are adequate; this fiber could be a better choice than the PP/PMP fiber.

PP and PAN are on opposite ends of a triboelectric series, and when they are rubbed against each other, as in needle punching, they develop opposite charges. Therefore, both polymers are good at holding these charges over long periods. The common name for a material that holds an induced charge is "electret." Electret air filters are made entirely with PP fibers, and these filters the positive and negative charges are carried on opposite sides of each PP fiber. This limits the strength of the charge, particularly where the fibers are very small in diameter, however, recently, even these newer PP/PAN filters are made from relatively large diameter fibers.

2.6. Ultra fine-Binder Fiber

Another form of a splittable fiber is as a ultra fine-binder fiber. The difference in melt temperature of the two polymers is playing significant role in manufacturing these fibres and in case this difference is large enough, the lower-melting of the two polymers can be used as a melt adhesive for the higher-melting fibers. Ideally, these fibers would be split apart before thermal bonding, either by splitting before forming the web, or by forming the web and then splitting the fibers.

PET and high-density polyethylene (HDPE) or linear low-density polyethylene (LLDPE) would be logical choices for components of a segmented ultra fine-binder fiber because these polymers are commonly used in sheath/core binder fibers.

Sheath/core fibers are excellent binder fibers in many applications, but they do not produce ultra fine fibers, and are not available in finer deniers. Therefore, wherever the need of small fiber diameters or high specific surface area in a thermally bonded fabric arises, a properly engineered splittable fiber is a better choice.Furthermore, it is also possible to blend splittable fibers with conventional binder fibers, using the splittable fibers to generate the ultra fine fibers and the conventional binder fibers to thermally bond the fabric.

The conventional binder fiber (either a sheath/core or a homopolymer binder fiber) supplies the binder material in relatively large amounts, larger areas of the fibers to be bonded are involved in the bond point. Conversely, the packets of binder material delivered by the conventional binder fiber are farther apart, so many fiber crossover points are left un-bonded.

The ultra fine-binder fiber does a better job of dispersing the binder material evenly throughout the fabric, without any concern for the uniformity of fiber blending, and delivers the binder material in appropriately-sized packets.

With the splittable ultra fine-binder fiber, the result is more, smaller bonds, which should result in a bonded fabric that is stronger at equivalent softness or softer at equivalent strength. Under the right conditions, a ultra fine-binder fiber could provide a fabric that is simultaneously both stronger and softer than a comparable fabric made with conventional binder fibers.

2.7. Elastomeric Splittable Fibers

This is a fibre made with PP and thermoplastic polyurethane which is chemically-resistant splittable segmented fiber. Polyurethane have pretty good chemical resistance, and do not have good adhesion with PP.

The fiber can be drawn and even crimped and cut without splitting. In the drawn state, the PP is plastically deformed – that is, it stays drawn even under no stress. The PU segments, though, are elastically deformed, and are held in their stretched state only by the reasonably high friction with the surfaces of the PP segments.

Only a small force is required to release the hold one polymer has on the other, and the resulting contraction of the PU (if the splitting is done under relaxed conditions) splits the wedges apart. It has shown that one can initiate this splitting simply by exposing the fibers to heat, and this concept is valid for any combination of one elastomer and one non-elastomer with poor mutual adhesion.

3. Applications of ultra fine denier fibres

These fibers are commercially available today. They are most often used in making synthetic suedes and synthetic leathers. In the case of synthetic leathers, a subsequent step introduces coagulated polyurethane into the fabric, and may also include a top coating. Another the end-use that has elicited interest in pie wedge fibers is in technical wipes, where the small fibers are useful for picking up smaller pieces of dust.

The most probable application of the PP/PAN electret fiber is in air filtration. Some of the most efficient air filters made today is needlepunched webs of blended PP and PAN fibers. These filters are more efficient because there is less chance of charge neutralization within the fibers, so the charge on individual fibers can be higher. The splittable fiber shown here could simultaneously provide both the dual electrets and ultra fine fibers, resulting in an even more efficient filter medium.

4. Conclusion

With the use of modern multicomponent technology, ultra fine denier fibers with a dpf of less than 0.2 can now be produced and processed economically and in large quantities. The industry is no longer limited in fiber dpf to the lowest homo polymer denier that can be spun or processed into fabric with reasonable yields. It is expected that exciting new products will be constantly discovered using this technology in the next decade.

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