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CRITICAL FACTORS IN ENGINEERING SEGMENTED BICOMPONENT FIBERS FOR SPECIFIC END USES

by

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CRITICAL FACTORS IN ENGINEERING SEGMENTED BICOMPONENT FIBERS FOR
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Just as nonwovens are discovering new growth opportunities by engineering specific properties into the fabric, we are engineering specific performance characteristics into staple fibers for use in these fabrics. Recently, we've applied this approach to splittable segmented bicomponent fibers. Some of the most intriguing results from that work are reported here.

Status Quo Splittable Fibers

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 which simultaneously split the fibers into individual wedges, and entangle the fibers to give the fabric strength and integrity. As a result, the fabric contains fibers down to 0.2 denier per filament, but most of the throughput and processing advantages of a 3 denier fiber are maintained.

Figure 1

PET

Nylon
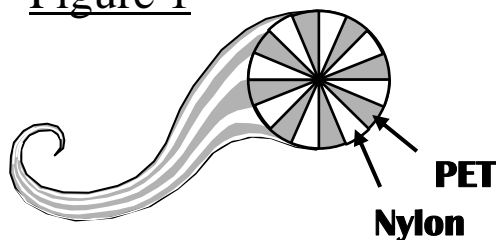
Standard pie wedge fiber

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 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. Finally, the fibers are also being evaluated for use in filtration. This application is somewhat limited by the fact that commercial splitting processes have so far been limited to hydroentangling.

The best reason to use nylon and polyester (PET) for these fibers is that the two polymers have sufficiently little adhesion to each other 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.

Problems with Nylon and PET

But nylon and polyester are not ideal for all uses. In fact they are not even ideal for the applications in which they are currently used. In synthetic suedes, the fabric is often dyed. Since both the nylon and

the polyester must be dyed, two separate dyeings must be performed. And because two different types of dye are used, metamerism can be more of a problem than if only one type of dye were used. That is, the two types of dyes may appear as different shades under incandescent, 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 of the fabric will shift as it fades. If an all-polyester fabric 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 hue as all the others. It would be ideal to make the fiber entirely with polyester. But PET and other polyesters or copolyesters have too high an adhesion to each other to be easily separated from a segmented fiber. So PET and nylon represent a compromise.

In filtration, the problem is not with dye shades, but with the chemical resistance of the polymers. Of course, for drinking water, or some food filtration, this is not a concern. But when filtering corrosive fluids, polyester and nylon often are too susceptible to degradation or dissolution in the stream being filtered. In these cases, 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 polypropylene. 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. It is plausible that chemical resistance might be important in a wipe, too, but I am not aware of specific examples where this is the case.

Engineered Solutions

With ingenuity and a versatile process, though, there are ways to solve the problems of conventional splittable fibers. Lets take a look at some of the things we can do to tailor the fiber's performance to its end-use.

The most important thing a splittable fiber should do is to split. To ensure splitting, we must start with dissimilar polymers. But even after 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

Figure 2

Segmented ribbon

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 when high splittability is required, these are the cross sections to use.
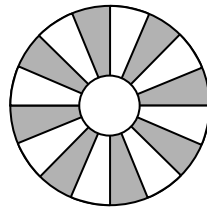
Figure 3
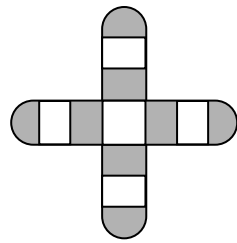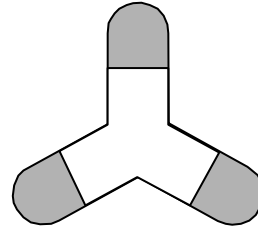
Segmented cross   Tipped trilobal

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. The easiest round cross section to split is the hollow pie wedge shown in Figure 4. It also requires relatively expensive
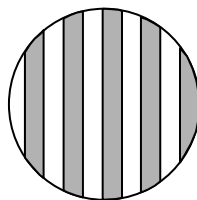
Figure 4

Hollow pie wedge

spinnerets, but it is often a good cross section for polymers 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.

Figure 5

Conjugate

Sometimes referred to as a conjugate fiber, this fiber is likely to split easily when the splitting forces, such as from hydroentangling jets, are applied in parallel with the segment edges, but would split less easily under forces applied perpendicular to the segments.

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, if we wish to minimize the fiber's materials cost, we can optimize the polyester content, as shown in Figure 6. 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 7. 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 like those shown in Figures 6 and 7.

Figure 6   ## Figure 7
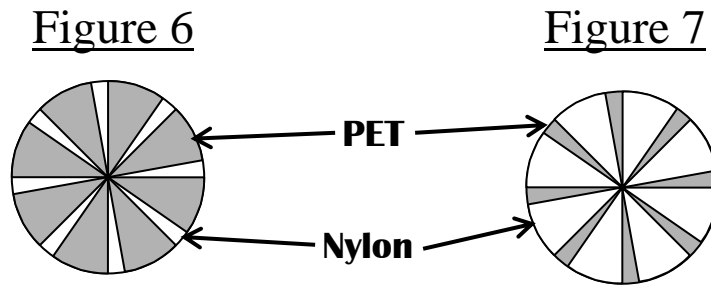
Even more productive, in our experience, is the substitution of entirely different materials for the polyester and nylon. Though we are limited to melt-spinnable polymers, there is still a wide array of properties available beyond those provided by "plain vanilla" PET, nylon, and polypropylene. Several new fibers that have resulted from our efforts with modifying polymer content, polymer ratio, and cross section. These new fibers open the door to new functional possibilities in nonwovens made with the fibers.

All-Polyester Splittable Fiber

The first of these new fibers addresses the dye shade problem with nylon/polyester splittable fibers used in synthetic suede fabrics. We've had a difficult time trying to make an all-polyester fiber that would actually split. But we haven't spent all of our time on splittable fibers, and in some recent work with poly (lactic acid), or PLA, we found that PET and PLA split apart quite nicely. This is because even 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. So its surface energy differs significantly from that of other polyesters, and allows the two to split apart. However, PLA is enough like other polyesters that it can be dyed with the same disperse dyes used to dye PET. So now when the fabric fades, it will at least fade on-shade. The disperse-dyeability of PLA also leads to the possibility of transfer printing the synthetic suede, if a high-T_m 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. On top of all this, the use of PLA does not sacrifice any strength or resilience previously supplied by the nylon, and may even provide a cost advantage.

At the time this paper was written, a quantitative comparison of the dye performance of PLA and PET, and a study of the transfer-printability of PLA were underway. Final results should be available by the time the paper is presented.

All-Polyolefin Splittable Fiber

Long before we discovered a way to make an all-polyester splittable fiber, we had been trying to find a way to make an all-polypropylene splittable fiber, for use in filtration in corrosive environments. As with the all-polyester fiber, this turned out to be quite a tough nut to crack, and though we had some "almost-as-good" candidates, we were about to give up hope for a true all-polypropylene splittable

fiber. Then an experiment using poly(methyl pentene) (PMP) for an entirely different application ended in failure. But the failure of PMP in that fiber indicated that PP and PMP might split apart. And in fact, they do. 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°C, about 80°C higher than that of PP. So it is 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 one property of PMP that is regrettable is its cost. For this reason, we envision a cross section that minimizes the PMP content for most applications.

Dual Electret Splittable Fiber for Air Filtration

On the way to the PP/PMP fiber, we found some candidates whose chemical resistance and splittability were almost as good as those of an all-PP splittable fiber. One of these is made with PP and PAN (polyacrylonitrile, commonly called "acrylic"). PAN is not conventionally melt-processable, but we are working with a new thermoplastic copolymer that maintains an acrylonitrile content high enough to still qualify as an acrylic rather than a modacrylic. 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, but at least the fiber is not handicapped by the melt temperature of polyethylene, which might be a more obvious candidate for splitting with PP in a chemically-resistant fiber. PAN's cost is also 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.

An even more intriguing possibility for this fiber is in air filtration. Some of the most efficient air filters made today are needlepunched webs of blended PP and PAN fibers. PP and PAN are on opposite ends of a triboelectric series, and when they are rubbed against each other, as in needlepunching, they develop opposite charges. What's more, 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 made entirely with PP fibers are becoming more common, but in 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. The PP/PAN needlepunched filters are more efficient because there is less chance of charge neutralization within the fibers, so the charge on individual fibers can be higher. But even these newer PP/PAN filters are made from relatively large diameter fibers. The splittable fiber shown here could simultaneously provide both the dual electrets _and_ microfibers, resulting in an even more efficient filter medium.

So we've been able to engineer properties into splittable fibers to address the concerns with dye shade and chemical resistance that we identified for nylon/PET pie wedge fibers. As it turns out, there are other areas where splittable fibers can be useful, if they are engineered to achieve the specific performance required by the application.

Micro-Binder Fiber

One intriguing new use of a splittable fiber is as a micro-binder fiber. In most cases, because the segments must be sufficiently dissimilar to split apart, they are going to have some difference in melt temperature. If 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, the 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. Although we tend to think of the segments as splitting completely apart from each other, it is possible,

and perhaps even desirable, that the segments split apart in pairs – one higher-melting segment joined to a lower-melting segment. We believe this tendency can also be engineered into the fiber.

PET and high-density polyethylene (HDPE) or linear low-density polyethylene (LLDPE) would be logical choices for components of a segmented micro-binder fiber because these polymers are commonly used in sheath/core binder fibers. But if you want a chemically-resistant, thermally-bonded, microfiber fabric, we could replace the PET with PMP. And for lower cost and better bonding with PMP, the polyethylene could be replaced with PP.

Sheath/core fibers are excellent binder fibers in many applications, but they do not produce microfibers, and are not available in microfiber deniers. So where you need small fiber diameters or high specific surface area in a thermally bonded fabric, a properly engineered splittable fiber is a better choice.

But it is also possible to blend splittable fibers with conventional binder fibers, using the splittable fibers to generate the microfibers and the conventional binder fibers to thermally bond the fabric. The result of this approach is illustrated in Figure 8. Because 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 micro-binder fiber does a better job of dispersing the binder material evenly throughout the fabric, without any concern for the

Figure 8

Microfiber A

Binder

Microfiber B

Standard binder fiber
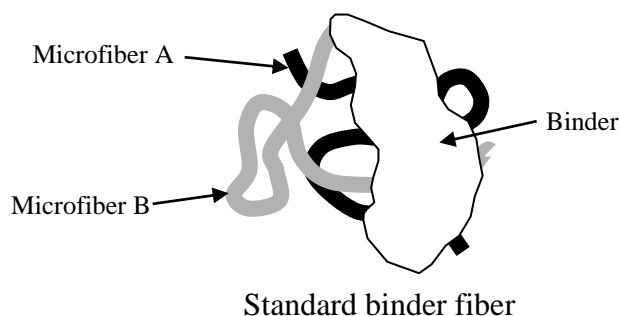
uniformity of fiber blending, and delivers the binder material in appropriately-sized packets (see Figure 9). Strengthening a fabric usually makes it less soft, and softening a fabric usually

Figure 9
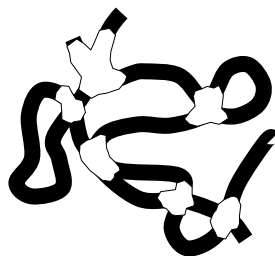
Micro-binder fiber

makes it weaker. But with the splittable micro-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 micro-binder fiber could provide a fabric that is simultaneously both stronger and softer than a comparable fabric made with conventional binder fibers.

Splittable Fibers for Wet-Laid Applications

There is considerable interest in splittable fibers for wet-laid applications. In the wet-laid process, the fiber does not need to be carded, so in many cases, it can be delivered already split. In addition, some parts of the wet-laid process can present unique opportunities for splitting the fiber if it is delivered un-split. Aside from splittability issues, the polymers used can be selected based on the requirements of the end-use. But even traditional fibers need to be cut very short, typically ¼ to ½ inch, to achieve a length/diameter ratio suitable for the wet-laid process. So if the fiber is going to be split before the fabric is formed, it must be cut even shorter, to address the length/diameter ratio needs.

Elastomeric Splittable Fibers

Finally, in our efforts to develop a chemically-resistant splittable fiber, we investigated a segmented fiber made with PP and a thermoplastic polyurethane. Polyurethanes have pretty good chemical resistance, and it turns out that they do not have good adhesion with PP. We were even more intrigued, though, with the way this fiber splits. 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 impetus 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. We have been able to initiate this splitting simply by exposing the fibers to heat. The concept was developed using PP and PU, but is valid for any combination of one elastomer and one non-elastomer with poor mutual adhesion.

This is most interesting for filament yarns, because as the PU contracts, the PP has nowhere to go but to bunch up around the PU filaments. The result is a self-bulking or self texturing microfiber yarn with elastic stretch. The PP bulks around the yarn's exterior, so if the PP is melt-colored with one color and the PU is melt-colored with a second color, the color of the yarn will change with the degree of stretch.

Some time after we had conceived this PP/PU splittable fiber, Hills, Inc. showed us a similar concept that they had developed. Their idea was a tipped trilobal fiber as shown in Figure 3, with an elastomeric center and nylon tips. This fiber also spontaneously splits apart when heated, and forms a nice textured yarn.

So how is this applicable to nonwovens? A hollow pie wedge PP/PU fiber can be crimped and cut into staple fiber, but the PU has a high enough fiber-to-metal friction to cause problems in carding. But the Hills fiber is one that does not allow the elastomer to come into contact with metal surfaces in processes like carding. To get smaller microfibers, we've adapted the multi-lobed cross section to a segmented cross (shown in Figure 3) to make a PP/PU fiber that should be cardable. Once the card web made with these fibers is bonded, if the fabric is heated under relaxation, we would expect the segments to split apart, forming a microfiber nonwoven fabric with elastic stretch recovery.

Summary

In summary, we have explored some of the ways that the basic nylon/PET pie wedge fiber can be re-engineered to achieve a wide variety of different performance characteristics, each useful in specific applications. We are doing similar things with sheath/core, islands in the sea, and other bicomponent cross sections. And there is more to report about further efforts with segmented fibers, but we'll have to leave that for another time.