

Key Performance Characteristics of Synthetic Textile Fibers

A polymer chemist describes the characteristics of the primary polymers used to make synthetic carpet face fiber: polypropylene, nylon and polyester.

>> by J.R. Webster, PhD



The diversity of synthetic textile fibers for carpeting and the diverse physical-chemical properties of the polymers used to make them have been the subject of much discussion in the last few years, as changes in manufacturing, backing design, and stabilization have complicated that picture.

Changes in manufacturing technologies, catalyst systems, additives and post treatments all add to the complexity of each polymer's performance as a textile fiber. This article examines the three primary synthetic polymers used in carpet face fiber, including subtypes of two of them. This examination will look beyond the fibers encountered by carpet cleaning professionals to the challenges faced in manufacturing the polymers which are extruded into polypropylene, nylon and polyester fibers.

Polypropylene (polyolefin)

Polypropylene is significantly different in its chemistry and production compared to

condensation polymers such as polyamides (nylon) and thermoplastic polyesters (PET, PTT). Polypropylene is produced by coordination polymerization which is a form of addition polymerization. The process for making polypropylene involves gas-phase reactions with a monomer and catalyst. The formation of the polypropylene in the reactor under pressure forms around the catalyst particles. The final powder form of polypropylene is white and further treatments to deactivate the resin are part of the manufacturing process.

Modern methods to deactivate catalyst are more problematic than in the past. In the past slurry liquid processes

allowed for deactivation with hydrocarbon solvents. Today it is more difficult in a gas-phase process and in many cases leaves the catalyst in an active state even after treatment. In addition, the type of catalyst used will determine downstream properties such as long-term thermo-oxidative stability and reactions with stabilizers to control degradation of the polymer.

Many generations of catalyst technologies have been used to refine polypropylene over the last sixty years. Each generation of catalyst has improved isotacticity and increased stereo regularity of the polymer. It has also changed the way polypropylene crystallizes and the nature of crystallization. It has allowed for more diverse structures and performance characteristics; this, in turn, has had both positive and negative effects on long-term thermo-oxidative stability (polymer degradation over time), ultraviolet (UV) durability, and additive interactions causing premature yellowing or discoloration in storage.

Thermo-oxidative stability, or long term aging, relates to the time it takes for the polymer to degrade and subsequently lose physical property integrity. This is a temperature-dependent reaction and is influenced by contact with chemicals, transition elements, oils, lubricants, soaps and any other chemicals or substances that come in contact with the polymer. Thickness of the polymer weighs heavily on the rate of degradation. The thinner the polymer the more rapid the degradation at a set temperature. Furthermore, residual peroxides in the vis-breaking (post polymerization) process to increase melt flow and narrow molecular weight distribution adds to the overall problems associated with long-term oxidative stability.

Degradation of polypropylene manifests itself in loss of physical properties of the polymer and to a lesser extent discoloration. Discoloration and degradation of polypropylene are not necessarily related to the loss of physical properties but are more likely due to base-catalyzed reactions by chemicals and additives on the stabilization system used to maintain processing

these stabilizers cause in-situ formation of transformation products that give colored byproducts. In the presence of basic (alkaline) cleaning chemicals, they react to form intense chromophores which range from yellow, orange and red to green and blue. This reaction is typically but not exclusively topical in nature due to the migration of low concentrations of these ad-

only address two forms: nylon 6 and nylon 6-6, which are the primary textile fibers used in carpet. Nylon 6-6 was the dominant nylon used in carpet for many years. The advantage has typically been seen in physical properties over nylon 6. However, with advances in manufacturing and post-polymerization techniques, both are now fairly comparable in physical properties. In

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and long-term oxidative stability. Changes in the technology for making polypropylene also alters the residual catalyst and the state of that catalyst on the stabilizers used to provide protection to the polymer. These changes in the last few years have demonstrated the need for better stabilizer systems and a better understanding of acid buffers to stabilize the polymer over time.

Ultraviolet (UV) durability of polypropylene is a constant challenge. The advent of hindered-amine technologies have significantly improved the durability of the polymer but are also attacked by some carpet cleaning chemicals — including acid rinses — and other acidic chemicals that reduce their efficacy in providing long-term UV protection to carpet fibers. Hindered-amine light stabilizers are typically more basic (alkaline) additives and are adversely inhibited from functioning in acidic environments.

The major utility of the hindered amine is to protect the fiber from physical property loss and not discoloration. In natural, unpigmented polypropylene, discoloration is more typically related to the aromatic stabilizers used to provide for processing and long-term oxidative degradation. The mode of action of

additives to the surface of the carpet fibers.

Discoloration can also occur due to gas staining (also referred to as gas yellowing and gas fading). This reaction is a surface reaction by prompt oxides of nitrogen formed from burning propane gas or from gas-fired ovens and gas-fired fireplaces in homes. The many forms of discoloration of polypropylene are diverse and is a broader subject than can be covered thoroughly in this article. In summary, additive interactions with the stabilizers from internal and external sources in polypropylene are the major sources for discoloration.

The major limitation of polypropylene for carpets has been its resiliency or “bulk crush.” Polypropylene fibers do not recover as readily as nylon fibers. The cost of polypropylene is also a factor in the market today. The past cost-performance advantages due to lower-cost raw materials is no longer a key advantage over the nylon and polyester polymers. Thus, polypropylene’s use in carpet fiber has declined in recent years.

The Nylons

As previously mentioned, nylon (polyamide) is a condensation polymer and exists in several chemical forms. We will

recent years a trend has been toward nylon 6 from nylon 6-6, due to production and raw material cost advantages. In addition, we have seen greater changes in nylon 6 in the last few years with new technological developments in post-polymerization additives that alter the molecular properties of the textile yarn while significantly improving soil resistance, bleach resistance and outdoor durability.

In the past, the focus has been on nylon coloration. The stabilizers and additives used to produce nylon carpet fibers have been less diverse than in polypropylene fibers due to market forces. The market considered polypropylene as the dominant high-volume fiber when polypropylene prices were low. Therefore, additive-development efforts were limited and nylon had fewer options to select from. Essentially, all improvements came from the manufacturer of the nylon fiber.

As is the case with polypropylene, nylon carpet fibers contain hindered-amine light stabilizers, which are equally compromised by certain carpet cleaning chemicals — including acid rinses. Nylon carpet fibers are highly susceptible to physical property degradation by the use of chlorinated bleach-type chemicals. Whether nylon is

piece dyed or solution dyed, bleach will damage its overall physical properties and damage or destroy the color in the fiber.

Solution-dyed nylon fibers are produced by melt-compounding colorants from master batch during fiber spinning. Piece-dyed carpet fibers are produced after unpigmented fibers are produced and placed into dye baths under conditions of temperature and pH adjustment to introduce the dye into the surface layers of the fiber. Differential piece dyeing allows greater penetration of the dye into the fiber. Piece-dyed carpet fibers are highly susceptible to fading and reaction by chlorinated chemicals to cause destruction of the colorant.

Nylon degradation is partly influenced by impurities and degradation products formed during manufacturing. In addition, the thermal-oxidative stability of nylon is a reflection of the inherent stability of the monomers used to produce nylon. Thermo-oxidative degradation is faster in the presence of moisture. Thin carpet fibers undergo faster oxidation in the presence of moisture. Nylon 6 especially under stress in the presence of moisture degrades faster than nylon 6-6

Crystallinity also determines the rate of penetration of cleaning chemicals.

In general, nylon is considered to have excellent chemical resistance. The reactions that occur happen when the end, amide and methylene groups react with simple organic compounds. The key here is the influence of solubility in the reaction medium or in the reactants themselves. Once molecular contact is effected, the reaction(s) can be made to proceed quite readily. Factors such as crystallinity of the fiber and the rate and extent of absorption of a solvent or reactant will greatly affect the facility of the reaction that occurs.

Yellowing of nylon is a problem as it is with polypropylene. However, since few if any phenolic antioxidants are added to nylon during processing, the type of yellowing that occurs is more intrinsic to the polymer. Photo yellowing or discoloration in the presence of UV radiation is one form, while thermo-oxidative degradation is another. Since carpet fibers are pigmented, this yellowing manifests itself in shade changes in the coloration of the carpet fibers on UV exposure. It is not uncommon for both classes of UV light stabilizer to have been added to carpet fibers past and

most commonly blended. These two classes of UV absorber can react with carpet cleaning chemicals to form chromophores such as phenolic antioxidants, so their presence can be a source of discoloration of pigmented nylon carpet fibers.

The change in coloration of carpet fibers from the diverse chemistries of dyes and pigments used in the industry is another problem when cleaning chemicals are used. Dyes are more susceptible to reaction by cleaning chemicals than high-end pigments used in solution dyeing of nylon. However, both classes have their limitations. Fading and changes in color are the two most dominant visual changes due to cleaning chemicals. Physical property loss after changes in coloration is the ultimate issue regarding the durability of the carpet. Visual changes always dominate while physical property loss over time is a problem that gets less attention until it is too late.

The physical-chemical characteristics of nylon have made it highly susceptible to damage by oxidizing agents, acids, and in some cases with alkali and inorganic metallic salts. The COOH and NH₂ groups in nylons are sensitive to light, heat, oxygen, acids and alkali.

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under the same conditions. Oxygen uptake of carpet fibers is less with nylon 6 than 6-6 which is in the order of decreasing crystallinity. Therefore, stretching of nylon fibers during the extrusion process reduces oxygen diffusion. The higher the stretch ratio the lower the oxygen diffusion and differences in crystallinity.

present. Today, hindered amines dominate as the means to protect nylon from photo yellowing, although in some cases combinations of UV absorber and hindered amines are used to protect select colorants used in nylon fibers. UV absorbers from the hydroxy-substituted benzophenone or hydroxy-substituted benzotriazole are the

Degradation is highly time/temperature dependent. Additives help control degradation. Nylons have excellent chemical resistance generally. Additional practices of sulfonation of nylon 6 fiber has provided significant improvements on the heat and chemical stability of the polymer. Control over transamidation

is another advancement in the stabilization of nylons.

Overall, the significance and severity of yellowing and physical property loss of nylon carpet fibers by cleaning chemicals is higher than that of polypropylene carpet fibers. In addition, post treatments with fluorinated chemicals is also a factor in long-term durability of the carpet fiber. Residual

conventional PET. Like all carpet fibers, the end-use performance depends on production and post treatments and the additives used. The trend to recycle polyester bottles and film to produce fiber also determines what is added to control end-use properties of the carpet fiber.

Thermoplastic polyesters are typically aromatic in nature. The major distinction

action initially during fiber spinning or on post drawing the fibers in storage.

Thermal degradation of polyesters occur via cleavage of the ester bond. PET is more stable than PTT. The ester cleavage is strongly influenced by certain catalysts. The type of catalyst will also determine the initial color of the polymer. Cobalt and antimony give a bluish grey color-

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PFOA (perfluorooctanoic acid), is a concern with all fluorinated carpet treatments.

The Polyesters

Thermoplastic polyesters (PET, PTT) are condensation polymers that have made a major resurgence in the last few years due to resin cost advantages and the environmental benefits of recycling the plastic. In addition, technological advances in controlling transesterification and intrinsic viscosity loss during fiber spinning, thereby maintaining the molecular weight of the fiber, has added to its utility by giving it a softer feel or “hand” while also maintaining higher physical properties to the textile fibers.

The introduction of PTT as a carpet fiber (polytrimethylene terephthalate) has given manufacturers an alternative to conventional PET (polyethylene terephthalate). Carpet fiber made from PTT is called triexta, a new fiber subclass approved by the Federal Trade Commission (FTC) in 2009. (The Shell brand is Corterra; the Dupont brand is Sorona.) Triexta combines some of the best properties of both nylon and PET. However, its intrinsic chemical resistance and soiling have similar limitations to that of

between the production of PET and PTT is the use of ethylene glycol in making PET while 1,3 propane diol is used to produce PTT. Unlike polypropylene, where molecular weight can be controlled to a much greater extent, the polyesters are limited to a maximum level of molecular weight in the reactor. Changes in molecular weight dramatically affect the physical properties of the polyesters. Impurities in the manufacture of the thermoplastic polyester also affect shade pigment matching and intrinsic photostability of the fiber.

The addition of colorants having various organic and inorganic chemistries, processing stabilizers and lubricants in colorant master batch, and other metallic impurities can adversely affect the polyesters’ molecular weight and physical properties over time. Cross-linking can be manifested by certain colorants during production due to the interaction of the pigment with the polymer at elevated temperatures. This interaction of additives and colorants with the polyesters limits their use as compared to polymers such as polypropylene. Additives for polyester must hold up at elevated temperatures, be polar soluble and have no chemical inter-

action to the resin. Aluminum impurities affect the red shade of the carpet fiber.

The stability of polyesters against hydrolysis is especially important during fiber spinning. A very small amount of water (100 ppm) can cause a decrease in viscosity and in molecular weight through hydrolytic sensitivity. Water concentration is so important because hydrolysis proceeds 104 times faster than thermal degradation and 103 times faster than thermo-oxidative degradation.

Although cost and environmental advantages have resulted in much greater use of the polyesters as carpet fiber, the drawbacks are the same as they have been from the beginning. These include the intrinsic instability of thermoplastic polyester to changes in pH during high temperature melt spinning which can be manifest in the carpet fiber produced. It has been shown that basic substances added during the melt processing of polyester have an adverse affect on the physical properties of the final fiber. The range of pH that causes this problem has never been fully quantified, but is fairly well understood in melt spinning. Clearly the more caustic the additives and colorant the more adverse to

the physical well being of the fiber. The more neutral the additive, the better to the properties of polyester.

The high temperatures and residence times used to produce polyester fiber puts major restrictions on the type of additives and colorants that can tolerate these conditions. The use of secondary antioxidants to control thermal degradation, rather than the phenolic antioxidants commonly used in nylon and polypropylene, results in fewer yellowing issues during storage. However, photo yellowing is an issue. Polyester fibers use both dyes and pigments as do nylon fibers. The dyes used in polyester fibers are brighter and more vibrant but typically fade faster than pigments used to color polyester fiber. Some of the same solutions are used to protect the polyesters from photo yellowing as with polypropylene and nylon, with the exception that hindered-amine light stabilizers are not used due to their intrinsic basicity and adverse effect on polyester fibers during melt spinning.

In general, due to the semi-crystalline nature of polyesters, their resistance to chemicals is considered excellent within a range of guidelines. Organic solvents, especially aliphatic hydrocarbons and alcohols and gasoline, ethers, long-chain esters, fats, oils and perchlorinated and fluorinated hydrocarbons do not affect thermoplastic polyesters at room temperature.

Polyester fibers are also resistant to weak bases and acids, water and aqueous solutions of neutral and acidic salts at room temperature. On the other hand, they are attacked by strong acids, oxidizing acids, strong bases, ketones and phenols. At temperature around and above 60C (140°F), thermoplastic polyesters are increasingly sensitive to monofunctional alcohols, aromatics, and ketones. However, they remain resistant to mineral and transformer oils, gasoline and brake fluids.

The major problems with polyester carpet fibers occurs during fiber production and what is produced determines how it will respond to carpet cleaning chemicals. Draw ratio affects crystallinity as does the molecular weight of the fiber

maintained during fiber spinning. The physical properties of the post-drawn fibers will depend on factors of post-draw ratio, remainder of spin finish in the fibers, annealing temperature and time, and the state of the additives and colorants used in the process of producing the carpet fibers. Factors such as shade of the color combination used — which could involve five or six colorants with varying degrees of solvent and chemical resistance — will influence visual color after cleaning but have no affect on the polyester fiber itself. Therefore, it is not exclusively about the polyester fiber but the total composition of ingredients added to the fiber that are being challenged.

Another characteristic of the polyesters, especially PET, is the propensity to manifest traffic paths — sometimes called traffic lane gray — starting early in its use-life. Satisfactory treatment of this condition has proved elusive for carpet cleaning professionals. The cause of this condition is the relatively low flex modulus, or bend strength, of the polyester fiber. A consequence of this is that in the high-traffic areas the fibers quickly transition from a perpendicular position to the floor to a more-or-less parallel one. Once these fibers are “flattened,” abrasion accelerates and soil particles become imbedded in the fibers.

There are pros and cons to each of the synthetic textile fibers. Their characteristics as polymers is significant, but equally

important are the additives, colorants and other ancillary products that are added to the polymer system. Together they determine the long-term durability of the fibers.

New chemistries to enhance both nylon and polyester fibers have been introduced in the last few years. These new chemistries allow nylon and polyester more chemical resistance by controlling reactions between carpet cleaning chemicals and the polymers. Since polypropylene has an intrinsic chemical resistance to a longer list of carpet cleaning chemicals, new developments in this area are limited to external lubricants. Implementation of these new chemistries is limited by cost and a commodity mindset. Frequently, quality improvements are put on the back-burner, as pressure to lower costs and price points dominates many market segments. ●

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