DuPont Tyvek

DUPONT TECHNICAL REFERENCE GUIDE FOR MEDICAL AND PHARMACEUTICAL PACKAGING

June 2017

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APPENDICES

This technical reference guide is published as of June 2017. DuPont reserves the right to modify testing per our change control procedures as needed to meet customer needs or to improve production control and efficiency.

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INTRODUCTION

DuPont™ Tyvek® for medical and pharmaceutical packaging delivers trusted protection

Since its introduction to the industry in 1972, DuPont™ Tyvek® brand protective material has been recognized as a standard of excellence for sterile medical packaging. Tyvek® earned this distinction because it provides a higher degree of microbial barrier and puncture protection for medical devices and supplies than other porous materials used for sterile packaging applications. The unique structure of Tyvek® gives it inherent advantages over other materials.

Helping speed up your compliance process

In this guide you will find extensive compliance data established by the DuPont network of regulatory affairs experts to help you develop and validate the most appropriate solutions with Tyvek®. This will allow you to meet worldwide regulations and packaging standards, while accelerating your product regulatory submissions and certifications.

Providing packaging science support

DuPont Packaging Engineers are available globally to support you with knowledge about materials, packaging design and processing to help optimize performance and total cost as well as to ease implementation.

LEARN MORE ABOUT THE SCIENCE OF PROTECTION WITH DUPONT™ TYVEK®

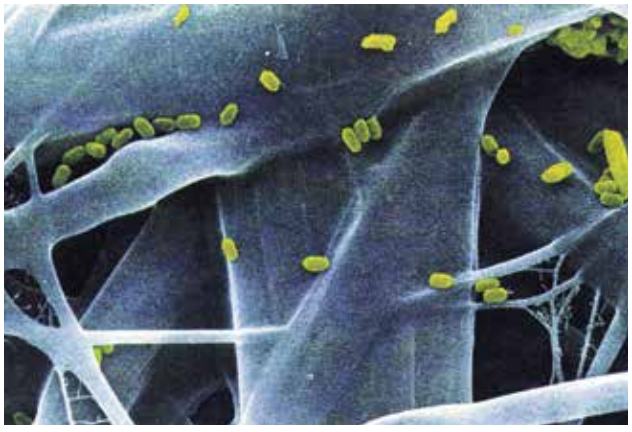
The unique structure of Tyvek® gives it inherent advantages over other materials, including:

Outstanding resistance to microbial penetration

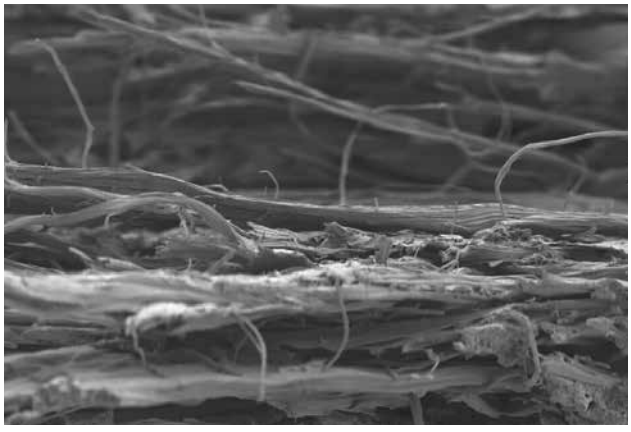
Microbial barrier test data consistently prove that Tyvek® holds out bacterial spores and test particles better than other porous packaging materials—even under the most rigorous conditions. In addition, a long-term shelf-life study proved conclusively that Tyvek® can maintain sterility for at least five years if package integrity is not compromised. The photomicrographs shown here illustrate how bacteria are trapped on the filament surfaces of Tyvek®.

Significantly reduced risk of package failure

The tough, continuous fibers of Tyvek® help protect package integrity from both product breakthrough inside and rough handling outside. Tyvek® is so tough, it resists punctures—even from the irregular or sharp edges of many surgical devices. Compared to medical-grade papers, Tyvek® has superior tear strength and puncture resistance.



Microbes trapped on filament surfaces of Tyvek® (500x magnification)



Cross-sectional view of Tyvek® (500x magnification)

Figure 1. Scanning electron micrographs (SEMs) of DuPont™ Tyvek®.

The unique structure of Tyvek®, which creates a tortuous path with substantial lateral movement, results in superior microbial barrier protection.

What's more, because it is breathable, DuPont™ Tyvek® minimizes the formation of condensation due to temperature extremes that can occur during transport. This breathability also allows medical packages made with Tyvek® to equilibrate rapidly from the pressure changes that occur not only during shipping but also in storage environments.

Low risk of device contamination

The unique structure of Tyvek® generates very few airborne particles when packages are opened or handled. This clean peel minimizes the risk of introducing particulates into a clean environment.

Compatibility with a broad range of sterilization methods

Only Tyvek® is compatible with all of the most commonly used sterilization methods. No matter which process you use: ethylene oxide (EO), gamma, electron-beam, steam (under controlled conditions) or low-temperature oxidative sterilization processes, Tyvek® will retain its superior protective properties of microbial barrier and strength, as well as its color and flexibility.

Helps you meet your environmental goals

As for ecological responsibility, Tyvek® is an excellent choice. This lightweight, durable material is an effective way to conserve resources and demonstrate environmental stewardship. Tyvek® is produced under verified environmental management policy according to ISO 14001. It can be recycled at local recycling facilities that accept high-density polyethylene (HDPE) waste according to local legislation. The items sent for recycling must not have been in contact with any hazardous substance.

AT THE FOREFRONT OF TECHNOLOGICAL AND REGULATORY DEVELOPMENT

An industry and technology leader

As leaders in the industry, we are dedicated to sharing information and expertise on topics ranging from industry standards and regulatory compliance to technical issues and quality. We develop and participate in conferences to help the industry stay on top of standards, regulations and new technologies. In addition, members of our team regularly participate on activities within:

- ASTM International
- International Organization for Standardization (ISO)
- European Committee for Standardization (CEN)
- Association for the Advancement of Medical Instrumentation (AAMI)
- Standardization Administration of the People's Republic of China (SAC)
- Japanese Standards Association (JSA)
- Sterile Barrier Association (SBA)
- Parenteral Drug Association (PDA)
- Healthcare Plastics Recycling Council (HPRC)

Contact our experts

If you have questions or need additional support with submission challenges, troubleshooting, analytical services, as well as packaging and regulatory compliance, contact your local DuPont representative.

WHY DUPONT™ TYVEK® IS UNIQUE

The unique structure of DuPont™ Tyvek®—tough, continuous filaments—creates both a tortuous path for superior microbial barrier and excellent strength properties.

Made of high-density polyethylene (HDPE), Tyvek® offers all the best characteristics of paper, film and fabric in one material. This unique balance of properties, which cannot be found in any other material, makes Tyvek® lightweight yet strong; vapor-permeable, yet moisture- and chemical-resistant; as well as puncture-, tear- and abrasion-resistant. Tyvek® is also low-linting, smooth and opaque.

Specification properties of Tyvek® styles for medical and pharmaceutical packaging applications can be found at the following links.

Specification Properties of Tyvek® 1073B and 1059B — English and Metric

Specification Properties of Tyvek® 2FS™ — English and Metric

Miscellaneous properties of Tyvek® styles for medical and pharmaceutical packaging applications can be found at the following links.

Miscellaneous Properties of Tyvek® 1073B and 1059B — English and Metric

Miscellaneous Properties of Tyvek® 2FS™ — English and Metric

It is important to note that these properties are for uncoated Tyvek® as sold by DuPont. Any downstream operations, such as coatings applied by sterile packaging manufacturers (SPMs), may change these values.

A description of the test methods used for these specification and miscellaneous properties can be found in Appendix 1.

Specification vs. other properties

Specification properties are typical values based on roll averages, with samples taken uniformly across the sheet. Specification properties are controlled to a nominal value and released within release specifications. The values for other properties are typical but carry no warranty, expressed or implied. For medical and pharmaceutical packaging, specification properties are basis weight, Gurley Hill porosity and delamination.

All other properties are the result of keeping the three specification properties on aim. Sampling plans for both specification properties and for miscellaneous properties are described in Appendix 2.

A miracle of science from DuPont

The discovery of Tyvek® was a chance occurrence by a DuPont researcher, Jim White, who in 1955 noticed white polyethylene fluff coming out of a pipe in a DuPont experimental lab. After examining this material, it was found that it had some very interesting properties. A program to develop the new material was set up, and a year later DuPont submitted a patent proposal for strong yarn linear polyethylene.

The proprietary flash-spinning technology, which is the basis for what was to become a new engineered sheet structure from DuPont, took several more years to perfect. In 1959, a pilot facility was established for trial applications such as book covers, tags, labels and certain garments. In 1965, the new engineered sheet structure was registered under the trademark name Tyvek®, but it was not until April 1967 that commercial production of Tyvek® started.

WHY DUPONT™ TYVEK® IS UNIQUE

Flash-spinning and bonding process

Tyvek® is formed by a fully integrated process using continuous and very fine filaments (having an average diameter of 4 μ) of HDPE that are randomly distributed and non-directional. (For purposes of comparison, a human hair is approximately 75 μ in cross section.) These filaments are first flashspun, then laid as a web on a moving belt before being bonded together. By varying the flash-spinning and bonding process conditions, DuPont can engineer the sheet properties to meet specific market needs.

Tyvek® for medical and pharmaceutical packaging applications is neither corona treated nor anti-stat treated because these treatments may compromise the barrier characteristics of Tyvek®. The styles of Tyvek® designed for use in medical and pharmaceutical packaging applications are: Tyvek® 1073B, Tyvek® 1059B and Tyvek® 2FS™. These styles are manufactured to rigorous quality standards to meet the unique requirements for medical and pharmaceutical packaging applications.

DUPONT™ TYVEK® VS. MEDICAL-GRADE PAPERS: A COMPARISON OF PROPERTIES

DuPont™ Tyvek® offers an optimum balance of microbial penetration resistance, tear strength, puncture resistance and clean peel, as well as compatibility with all of the most commonly used sterilization methods, including: ethylene oxide (EO), gamma, electron-beam, steam (under controlled conditions) and low-temperature oxidative sterilization processes.

The secret to the superior performance of Tyvek® is that it's not a paper, but rather a sheet of flashspun and bonded high-density polyethylene (HDPE) filaments. Continuous strands of very fine, interconnected filaments are randomly oriented and bonded together by heat and pressure during manufacture. The result is a tough, durable sheet structure that provides a unique combination of physical properties that no other sterile packaging material can match.

Tyvek® has become a standard of excellence against which other sterile packaging materials are judged. Tyvek® consistently outperforms medical-grade papers in tests for microbial barrier, tear and puncture resistance, liquid resistance, and particle generation (Figures 2 through 9).

Excellent barrier to microbial penetration

The number-one priority in selecting packaging materials for medical devices is the ability of the package to maintain sterility from the point of sterilization until the product is opened for use. Even under the most rigorous conditions in highly contaminated environments, Tyvek® is highly resistant to penetration by bacterial spores and other contaminating microorganisms.

Particulate and bacteriological tests clearly demonstrate that Tyvek® outperforms other commercially available porous packaging materials, including medical-grade papers (Figures 2 through 4). Comprehensive shelf-life studies have shown that Tyvek® can maintain sterility for at least five years if package integrity is not compromised. (See Section 5, "Performance of DuPont™ Tyvek® after Aging," for details.)

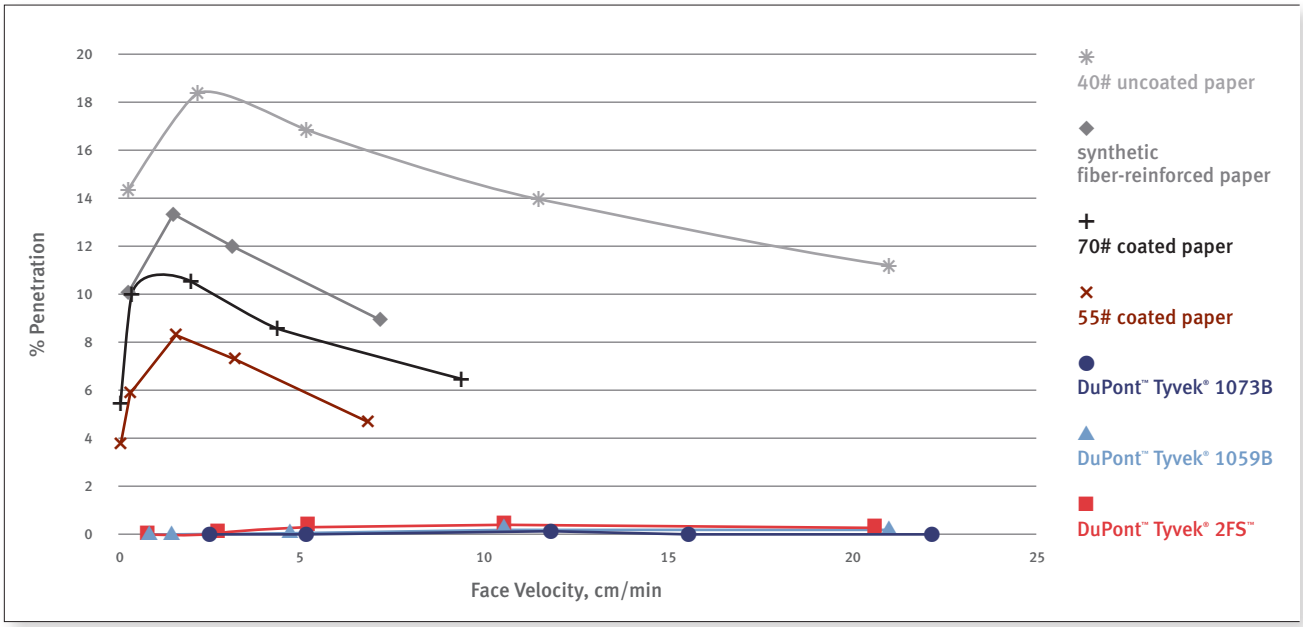


Figure 2. Particle penetration of porous sterile barrier materials (ASTM F2638).

ASTM F2638 *Standard Test Method for Using Aerosol Filtration for Measuring the Performance of Porous Packaging Materials as a Surrogate Microbial Barrier* measures the ability of a porous substrate to prevent particle penetration, which is highly correlated to microbiological spore penetration. All materials have a face velocity where maximum percent particle penetration occurs (pMax). The lower the percent penetration, the better the performance.

DUPONT™ TYVEK® VS. MEDICAL-GRADE PAPERS: A COMPARISON OF PROPERTIES

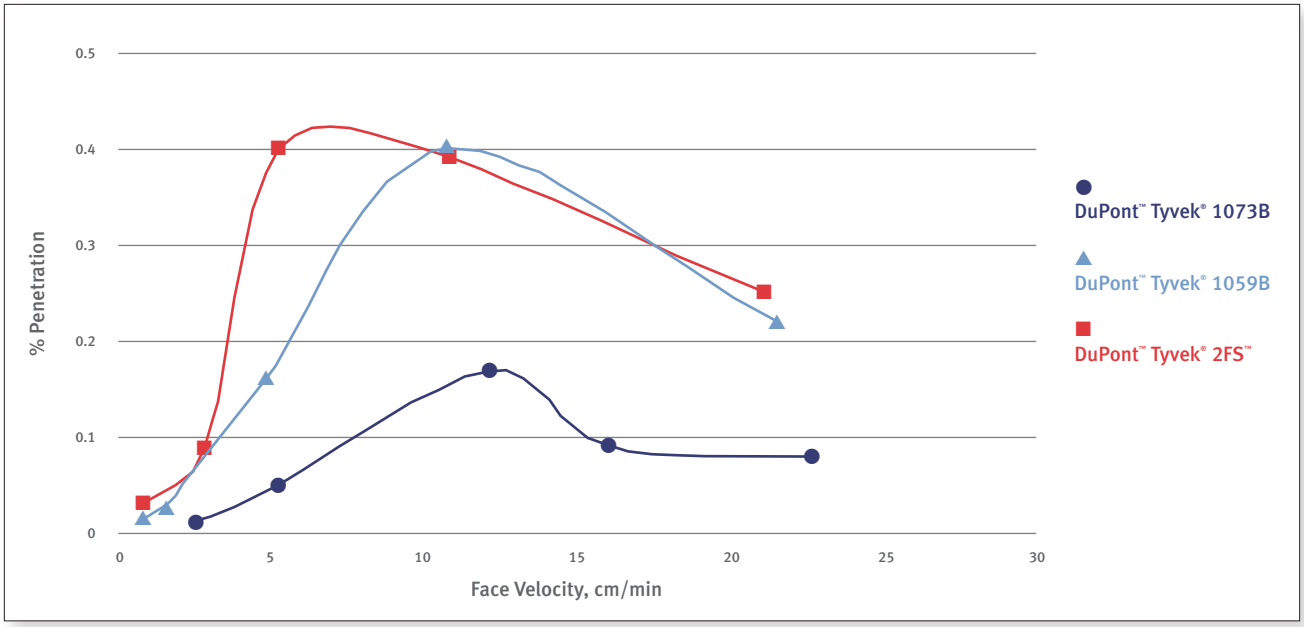


Figure 3. Particle penetration of DuPont™ Tyvek® medical and pharmaceutical packaging styles (ASTM F2638).

The percent penetration as a function of face velocity for Tyvek® 1073B, Tyvek® 1059B and Tyvek® 2FS™ demonstrates that these Tyvek® medical and pharmaceutical packaging styles all have a pMax of less than 0.5%. It is important to note the scale difference of the Y-axis compared to Figure 2. The pMax of other porous sterile barrier materials ranges from 8% to approximately 18%.

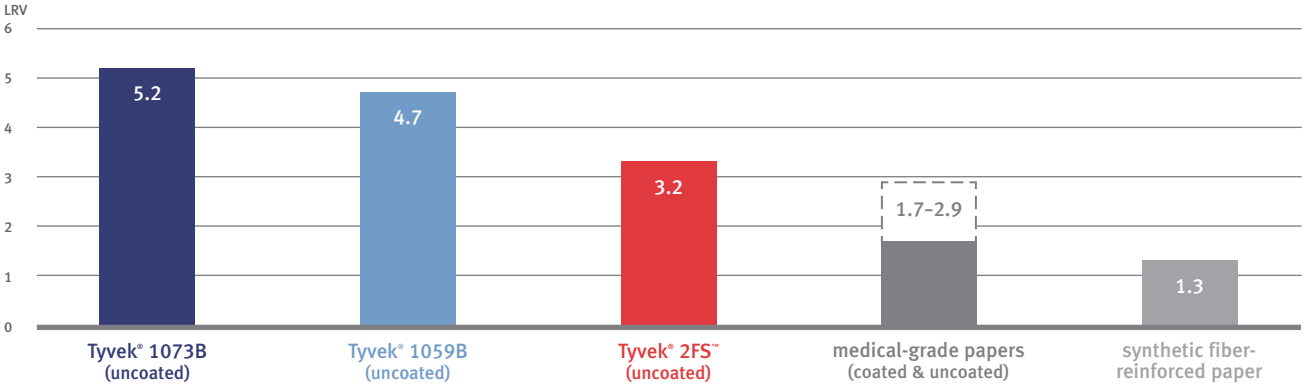


Figure 4. Microbiological barrier testing of sterile barrier materials (ASTM F1608).

ASTM F1608, Standard Test Method for Microbial Ranking of Porous Packaging Materials (Exposure Chamber Method), measures the ability of porous sterile barrier materials to prevent bacterial spore penetration. A completely impermeable control sample (microbial penetration is zero) is challenged with one million or 10^6 colony forming units (cfu). The number of cfu 10^6 has a $\log_{10}$ value of 6. If a sample challenged in the same way as the control allows 10 cfu (log 10=1) to penetrate, then its log reduction value (LRV) is 5 (6–1=5). Therefore, the higher the LRV, the more resistant the packaging is to microorganisms.

DUPONT™ TYVEK® VS. MEDICAL-GRADE PAPERS: A COMPARISON OF PROPERTIES

Superior tear strength and puncture resistance

The tough, continuous filaments of DuPont™ Tyvek® protect your package from product breakthrough and also from penetration by an object outside the packaging during rough handling. Compared to medical-grade papers, Tyvek® provides superior puncture resistance and tear strength, which means that Tyvek® does not puncture easily and tears do not readily propagate if a package is nicked.

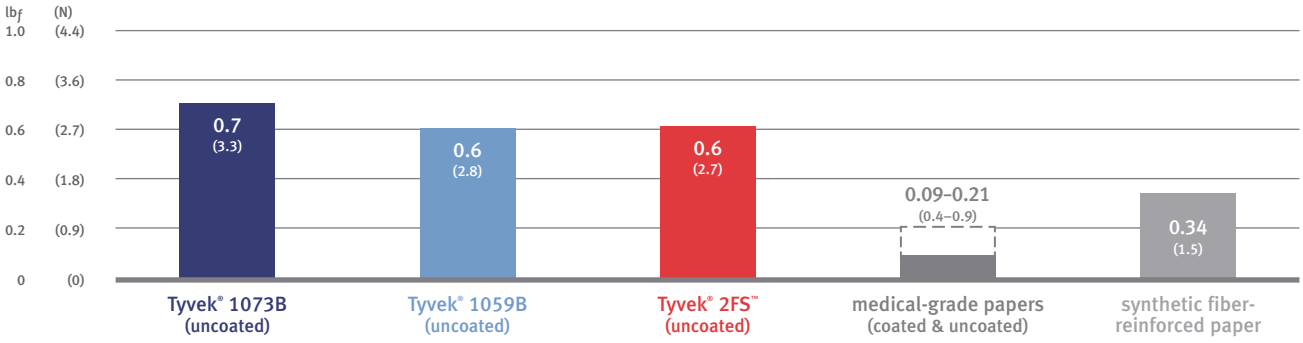


Figure 5. Elmendorf tear (MD) properties of DuPont™ Tyvek® styles and medical-grade papers (ASTM D1424 and EN 21974).

This test measures the force required to propagate an initiated tear from a cut or a nick. MD signifies machine direction. The higher the value, the less likely a material will tear under force.

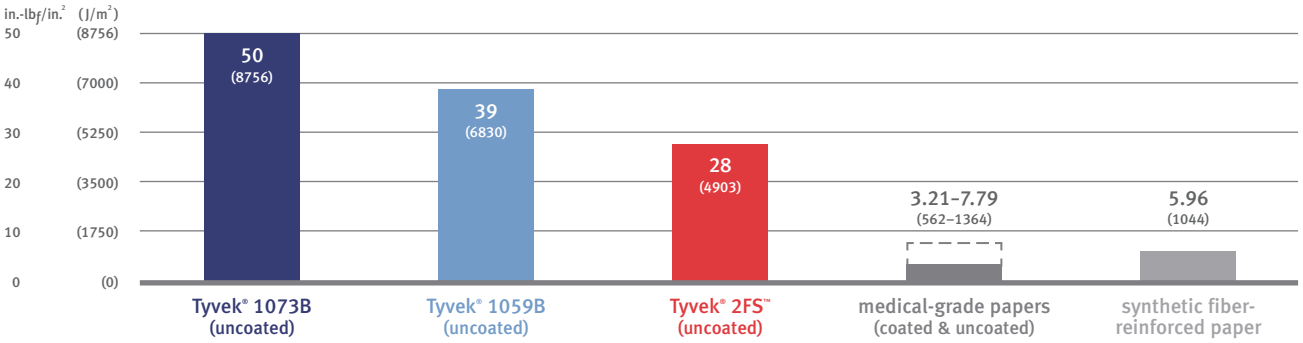


Figure 6. Spencer puncture properties of DuPont™ Tyvek® styles and medical-grade papers (ASTM D3420, procedure B).

This test determines the impact resistance of plastic films and packaging materials under conditions that closely approximate the strain rate that these materials are subject to in the healthcare industry. These results were obtained using a modified Spencer puncture test apparatus that features a 9/16-inch (14.3-mm) diameter hemispheric-shaped probe tip and a 6,400-gram pendulum, which is necessary to puncture tough materials like Tyvek®. Results using different test apparatus are not comparable.

DUPONT™ TYVEK® VS. MEDICAL-GRADE PAPERS: A COMPARISON OF PROPERTIES

Exceptional resistance to breakage

DuPont™ Tyvek® is an extremely flexible packaging material that won't break or tear as easily as medical-grade papers (Figure 7). This resiliency, combined with the inherent strength of Tyvek®, ensures that form-fill-seal packaging lines run smoothly and without significant downtime due to material web breaks.

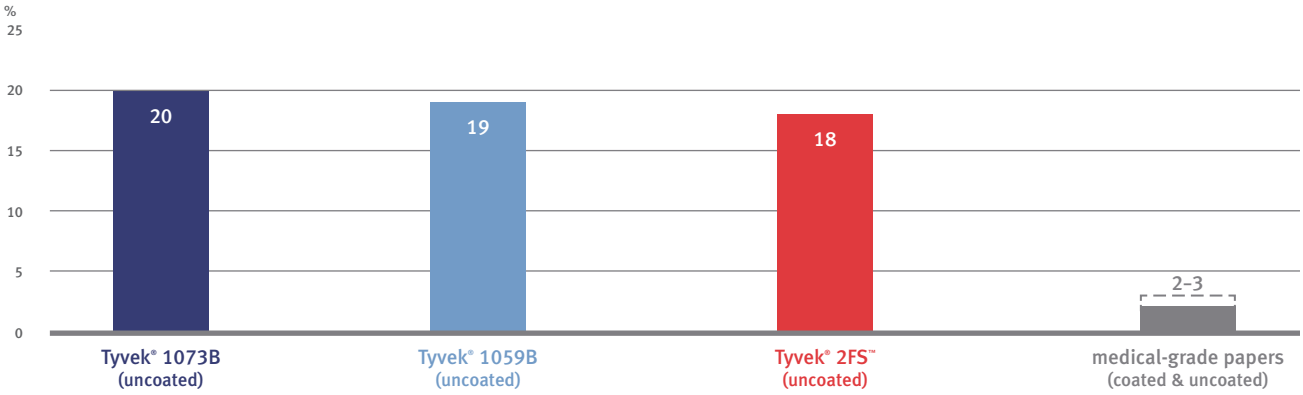


Figure 7. Elongation (MD) properties of DuPont™ Tyvek® styles and medical-grade papers (ASTM D5035 and EN ISO 1924-2 @ sample length of 5 in. [13 cm] and rate of extension [ROE] of 2 in./min [5 cm/min]).

Elongation is the measure of the extent a substrate will stretch before it breaks. MD signifies machine direction. The higher the value, the more a package will stretch before it breaks.

DUPONT™ TYVEK® VS. MEDICAL-GRADE PAPERS: A COMPARISON OF PROPERTIES

Outstanding moisture resistance and moisture vapor transmission

Unlike medical-grade paper, DuPont™ Tyvek® has outstanding moisture resistance. In fact, water in contact with Tyvek® does not wet its surface or spread; it simply remains as droplets on the surface. That's because Tyvek® is hydrophobic and does not absorb moisture, giving it distinct advantages compared to medical-grade paper.

For example, when medical-grade paper absorbs moisture, its strength and puncture resistance are reduced. This can greatly influence package performance, especially during distribution. In sharp contrast to medical-grade paper, Tyvek® maintains its superior strength both wet and dry.

In addition to its outstanding moisture resistance, another advantage of Tyvek® is that a high moisture vapor transmission rate (MVTR) can be achieved. This is particularly important for the ethylene oxide (EO) sterilization process where water is introduced as a vapor because moisture enhances the effectiveness of EO as a sterilant. Because medical-grade paper absorbs moisture vapor, it does not allow for a high MVTR across the material to the package contents.

Low-temperature oxidative sterilization processes, such as hydrogen peroxide gas plasma, cannot be used with cellulosic materials such as medical-grade paper because these materials rapidly interact with the oxidizing agent and its superoxide radicals. This can result in an aborted cycle due to inadequate sterilant concentration. Tyvek® is high-density polyethylene (HDPE) and allows for an effective sterilant concentration to be achieved. Although Tyvek® interacts only slightly with these types of sterilants, the surface energy is increased. This can cause a lowering of the hydrostatic head in industrial applications where multiple sterilization cycles are validated. The performance of Tyvek® as a sterile barrier is **not** affected but the liquid test methods for assessing package integrity (such as dye penetration and water immersion) can produce results that are different from untreated material.

Occasionally, medical device and pharmaceutical packages are subjected to adverse conditions that allow them to get wet, such as rain on a loading dock or flooding. When this occurs, the time of exposure and severity are not typically known. Because most device manufacturers label their packages as "sterile unless opened or damaged," we believe water contamination would constitute damage.

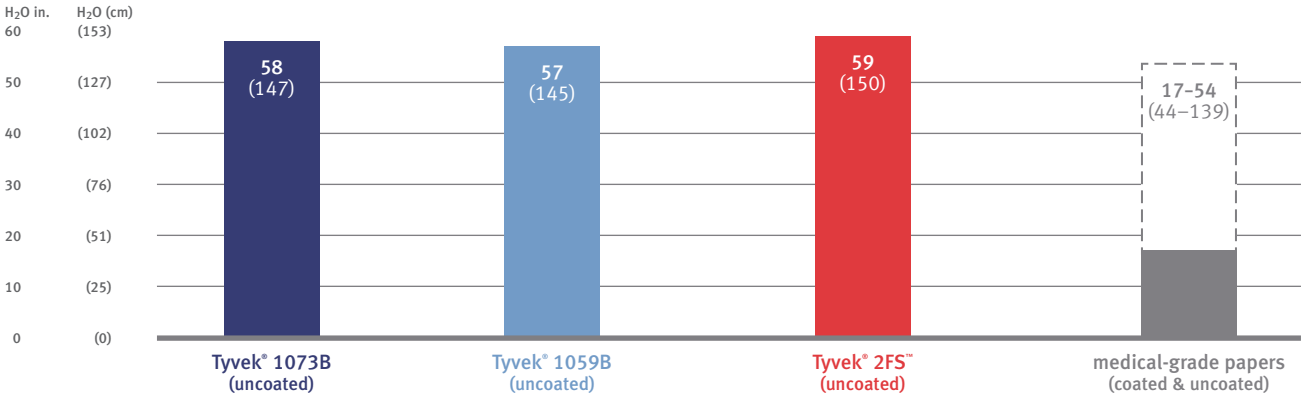


Figure 8. Hydrostatic head properties of DuPont™ Tyvek® styles and medical-grade papers (AATCC TM 127 and EN 20811 @ rate of use of 60 cm H_2O/min).

Hydrostatic head is the measure of the pressure required to force three drops of water through a substrate. The higher the value, the more resistant the package is to water penetration.

DUPONT™ TYVEK® VS. MEDICAL-GRADE PAPERS: A COMPARISON OF PROPERTIES

Clean peel

Unlike medical-grade paper, which can release a significant number of particulates when a package is opened, the unique continuous filament structure of DuPont™ Tyvek® results in clean peel and low lint features that minimize the risk of device contamination when packages are opened or handled. Tests were conducted to measure the quantity and size of particles generated by Tyvek® and medical-grade paper both before and after being torn in half (Figure 9).

Untorn Tyvek® samples generated fewer particles than paper across the entire size range from 0.3 µ to 10.0 µ. Paper generated 9,000 to 20,000 0.3 µ particles while Tyvek® generated less than 600. Once torn, the number of particles increased for all materials, with paper generating 19,000 to 35,000 0.3 µ particles and Tyvek® generating less than 1,000. This study provides conclusive evidence that Tyvek® generates significantly fewer airborne particulates that could contaminate either the medical device or the sterile field.

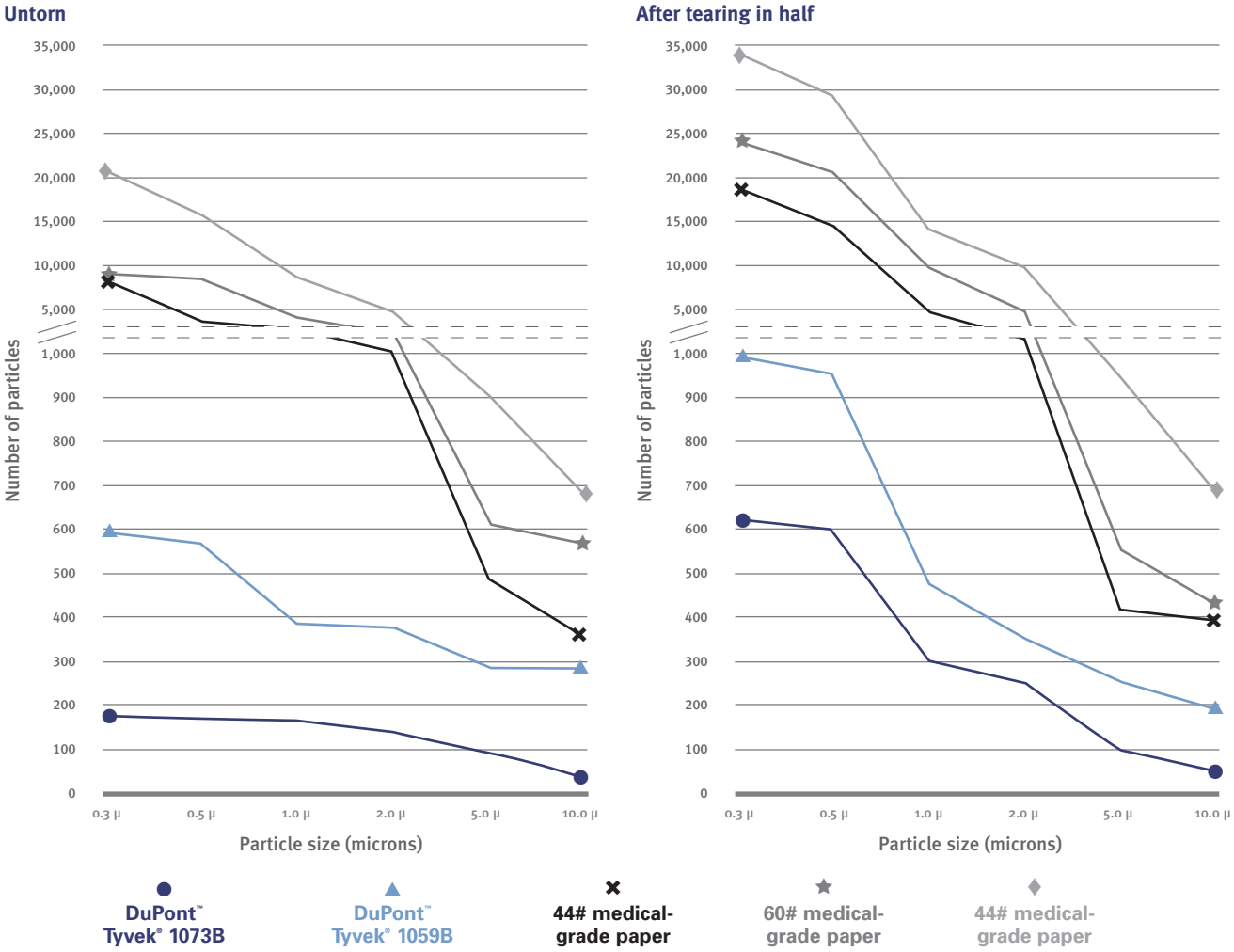


Figure 9. Particle generation properties of DuPont™ Tyvek® styles and medical-grade papers (as tested by an internal DuPont protocol).

For the particulate generation testing, samples (medical-grade papers, as well as Tyvek® 1073B and Tyvek® 1059B) were each tumbled in a tumbling drum to release particles from the tested materials. The drum was housed in a HEPA filter lab bench. The lab bench air was filtered with two pre-filters and one HEPA filter. Air was supplied by a blower with a pressure drop across the filters of 0.5 in. (1.3 cm) of water. Sampling of the number and size of the generated particles was done with a cleanroom monitor coupled to a paper tape printer. All of the equipment was housed in a temperature-controlled, HEPA-filtered-air cleanroom that had full air exchange approximately every minute.

COMPATIBILITY WITH STERILIZATION METHODS

Unlike medical-grade papers and films, DuPont™ Tyvek® offers sterilization compatibility with all of the most commonly used methods for sterilizing medical devices. These include: ethylene oxide (EO), gamma, electron-beam, steam (under controlled conditions), and low-temperature oxidative sterilization processes (e.g., STERRAD® Sterilization System). That's because Tyvek® is made of 100% high-density polyethylene (HDPE), which is extremely stable when exposed to sterilant gases and high-energy sterilization processes. In addition, Tyvek® is specially engineered to enable sterilant gases and steam to penetrate and escape quickly. No matter which of these sterilization methods is used, Tyvek® will retain its superior protective properties of microbial barrier and strength, as well as its color and flexibility.

Table I. Material compatibility with various sterilization methods

	DuPont™ Tyvek®	Coated, latex saturated medical-grade paper	All film package
Ethylene Oxide (EO)	Yes	Yes	No
Gamma Radiation	Yes	Yes	Yes[1]
Electron-beam Radiation	Yes	Yes	Yes
Steam	Yes[2]	Yes[3]	No
STERRAD®	Yes	No	No

1. May entrap undesirable odors inside the package.
2. Under controlled conditions (250°F to 260°F [121°C to 127°C]) at 30 psi for 30 minutes.
3. May become brittle.

COMPATIBILITY WITH STERILIZATION METHODS

Ethylene oxide (EO)

Ethylene oxide (EO) does not readily adsorb on DuPont™ Tyvek® and is released more rapidly than from cellulosic materials such as medical-grade papers, including synthetic fiber-reinforced paper (Figure 10). The superior strength and microbial barrier of Tyvek® are maintained after EO sterilization (Table II). Refer to Section 5, "Performance of DuPont™ Tyvek® After Aging," for test results after five-year real-time aging.

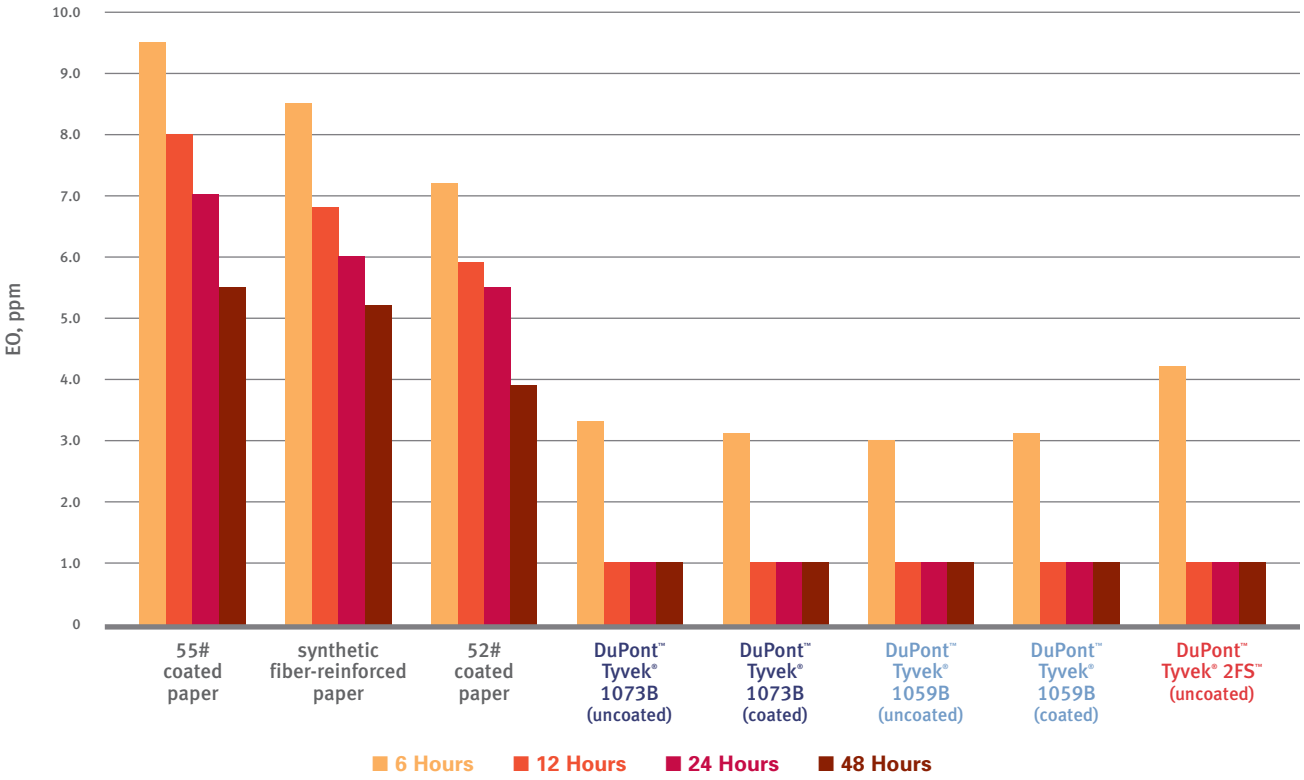


Figure 10. Ethylene oxide (EO) residual concentration in porous sterile barrier materials after sterilization and aeration for 6, 12, 24 and 48 hours. The residual analysis was conducted according to ISO 10993-7.

Table II. Strength and barrier properties before and after ethylene oxide (EO) sterilization

		Tensile Strength, MD[1] lbf/in. (N/2.54 cm)	Microbial Barrier, LRV[2]
DuPont™ Tyvek® 1073B	unsterilized	44.0 (196)	5.2
	sterilized	46.0 (205)	5.3
DuPont™ Tyvek® 1059B	unsterilized	37.0 (165)	4.7
	sterilized	35.0 (156)	4.7
DuPont™ Tyvek® 2FS™	unsterilized	31.0 (138)	3.6
	sterilized	33.0 (147)	3.3

1. Per ASTM D5035 and EN ISO 1924-2; modified for speed and gauge length.
2. Log Reduction Value (LRV) as tested per ASTM F1608.

COMPATIBILITY WITH STERILIZATION METHODS

Sterilization pouches and rolls intended for the healthcare sterilization market

Advanced Sterilization Products (ASP), Division of Ethicon Inc., a Johnson & Johnson company, has developed a complete range of self-seal pouches, heat-seal pouches and heat-seal rolls made with DuPont™ Tyvek® 4057B for use in the STERRAD® System.

ASP also prints a STERRAD® Chemical Indicator on its pouches and rolls to simplify the identification of processed packages. The STERRAD® Sterilization process is also used for industrial device sterilization with common package configurations using Tyvek® protective material. Caution should be used when choosing methodologies for package integrity testing after multiple cycles because the water penetration resistance of the material can be altered. For information about the STERRAD® System, including cycle time and performance details, visit http://www.aspjj.com/us

Radiation sterilization

Tyvek® maintains excellent microbial barrier properties and experiences only slight changes in tensile strength, elongation and color when exposed to radiation doses typically used in the medical device industry. Unlike other porous materials, Tyvek® resists post-sterilization brittleness and when packages are opened, Tyvek® maintains its low-linting performance.

Because Tyvek® is porous, undesirable odors produced by radiation sterilization can be aerated out of the package. Nonporous materials can trap these odors inside the packaging.

Another advantage of the porous nature of Tyvek® is that it allows medical packages to equilibrate rapidly from the pressure changes that occur during gamma sterilization.

It's important to note that although Tyvek® may withstand re-sterilization with either gamma or electron-beam, the device itself may not. If re-sterilization is required, gas sterilization can also be performed. Tyvek® will remain flexible after re-sterilization and will continue to provide an excellent microbial barrier.

Gamma

After exposure to gamma radiation up to 100 kGy, Tyvek® maintains its superior microbial barrier and the impact on strength properties is limited (Table III). These properties are also maintained after irradiation followed by exposure to accelerated and real-time aging (Section 5, "Performance of DuPont™ Tyvek® After Aging," Tables X through XII).

Table III. Results from tests comparing strength and microbial barrier of DuPont™ Tyvek® medical and pharmaceutical packaging styles both before and after gamma radiation at various doses*

			Tensile Strength, MD[1] lbf/in. (N/2.54 cm)	Microbial Barrier, LRV[2]
DuPont™ Tyvek® 1073B	unsterilized	—	42.0 (187)	5.2
	sterilized	25 kGy	39.1 (174)	5.2
		30 kGy	—	5.3
		50 kGy	35.8 (159)	5.2
		60 kGy	—	5.4
		100 kGy	23.1 (103)	5.1
DuPont™ Tyvek® 1059B	unsterilized	—	36.7 (163)	4.7
	sterilized	25 kGy	28.9 (128)	4.7
		30 kGy	—	5.1
		50 kGy	26.5 (118)	4.1
		60 kGy	—	4.5
		100 kGy	19.1 (85)	4.2
DuPont™ Tyvek® 2FS™	unsterilized	—	30.8 (137)	3.6
	sterilized	30 kGy	25.1 (112)	3.6
		60 kGy	21.2 (94)	3.4

*25 kGy and 30 kGy were single doses; all others were cumulative amounts from double doses (i.e., 50 kGy represents a double dose of 25 kGy, etc.).
1. ASTM D5035 and EN ISO 1924-2; modified for speed and gauge length.
2. Log Reduction Value (LRV) as tested per ASTM F1608.

COMPATIBILITY WITH STERILIZATION METHODS

Electron beam

After exposure to electron-beam radiation up to 100 kGy, DuPont™ Tyvek® maintains its superior microbial barrier and strength properties (Table IV). Specific studies of electron-beam sterilization followed by aging have not been conducted. However, we have not seen any effects other than those shown after gamma radiation and aging (Section 5, "Performance of DuPont™ Tyvek® After Aging," Tables X through XII) because HDPE is radiation stable.

Table IV. Results from tests comparing strength and microbial barrier of DuPont™ Tyvek® medical and pharmaceutical packaging styles both before and after electron-beam radiation at various doses*

			Tensile Strength, MD[1] lbf/in. (N/2.54 cm)	Microbial Barrier, LRV[2]
DuPont™ Tyvek® 1073B	unsterilized	—	42.0 (187)	5.2
	sterilized	50 kGy	35.8 (159)	5.2
		100 kGy	21.5 (96)	5.2
DuPont™ Tyvek® 1059B	unsterilized	—	36.7 (163)	4.7
	sterilized	50 kGy	30.4 (135)	4.9
		100 kGy	21.2 (94)	4.3

*50 kGy was a single dose; 100 kGy was a cumulative amount, representing a double dose of 50 kGy.
1. ASTM D5035 and EN ISO 1924-2; modified for speed and gauge length.
2. Log Reduction Value (LRV) as tested per ASTM F1608.

Hydrogen peroxide gas plasma

Based on test data and extensive long-term use, it is clear that Tyvek® 4057B is well-suited for use with the STERRAD® Sterilization System from Advanced Sterilization Products (ASP), Division of Ethicon Inc., a Johnson & Johnson company. This sterilization method uses low-temperature hydrogen peroxide gas plasma to enable sterilization of heat-labile devices.

Medical-grade papers, including autoclave paper pouches, are **not** acceptable for use with the STERRAD® System because cellulosic materials neutralize the sterilizing agent. Caution should be used when choosing methodologies for package integrity testing after multiple doses of low-temperature oxidative sterilization because the water resistance of the material can be altered. For more information about the STERRAD® Sterilization System, visit http://www.aspjj.com/us

Steam

Tyvek® has been shown to meet packaging criteria for steam sterilization under controlled conditions (250˚F to 260°F [121°C to 127°C] at 30 psi for 30 minutes). Packaging using Tyvek® for steam sterilization is commercial at medical device and pharmaceutical manufacturers.

Tyvek® continues to be superior to medical-grade paper when strong, low-linting packaging is required. Tyvek® retains its dimensional stability and integrity—with no discoloration—when steam sterilized under controlled conditions (250°F to 260°F [121°C to 127°C] at 30 psi for 30 minutes).

Tensile strength, microbial barrier and Gurley Hill porosity of Tyvek® are maintained after steam sterilization for 30 minutes at temperatures up to 260°F (127°C). (Table V).

Rigid or semi-rigid trays restrict potential shrinkage and wrinkling, which can result in a smoother/tighter lid. Shrinkage of Tyvek® after steam sterilization is less than 1.6% (Table V, Figure 11).

COMPATIBILITY WITH STERILIZATION METHODS

Table V. Physical properties of DuPont™ Tyvek® medical and pharmaceutical packaging styles both before and after steam sterilization

			Tensile Strength, MD[1] lbf/in. (N/2.54 cm)	Microbial Barrier, LRV[2]	Shrinkage Autoclave, %	Gurley Hill[3] sec/100 cc
DuPont™ Tyvek® 1073B	unsterilized	—	41.9 (186)	5.2	—	24
	sterilized 30 min.	250°F (121°C)	43.1 (192)	4.8	0.5	24
		255°F (124°C)	48.4 (215)	4.8	0.3	26
		260°F (127°C)	48.2 (214)	5.2	1.4	25
DuPont™ Tyvek® 1059B	unsterilized	—	35.2 (157)	4.7	—	19
	sterilized 30 min.	250°F (121°C)	36.0 (160)	4.7	1.0	21
		255°F (124°C)	38.7 (172)	5.1	0.5	34
		260°F (127°C)	40.2 (179)	4.1	1.5	23
DuPont™ Tyvek® 2FS™	unsterilized	—	27.8 (124)	3.6	—	18
	sterilized 30 min.	250°F (121°C)	26.7 (119)	3.1	0.8	20
		255°F (124°C)	28.5 (127)	3.1	0.3	20
		260°F (127°C)	29.1 (129)	3.3	0.9	17

1. ASTM D5035 and EN ISO 1924-2; modified for speed and gauge length.
2. Log Reduction Value (LRV) as tested per ASTM F1608.
3. TAPPI T460 and ISO 5636-5.

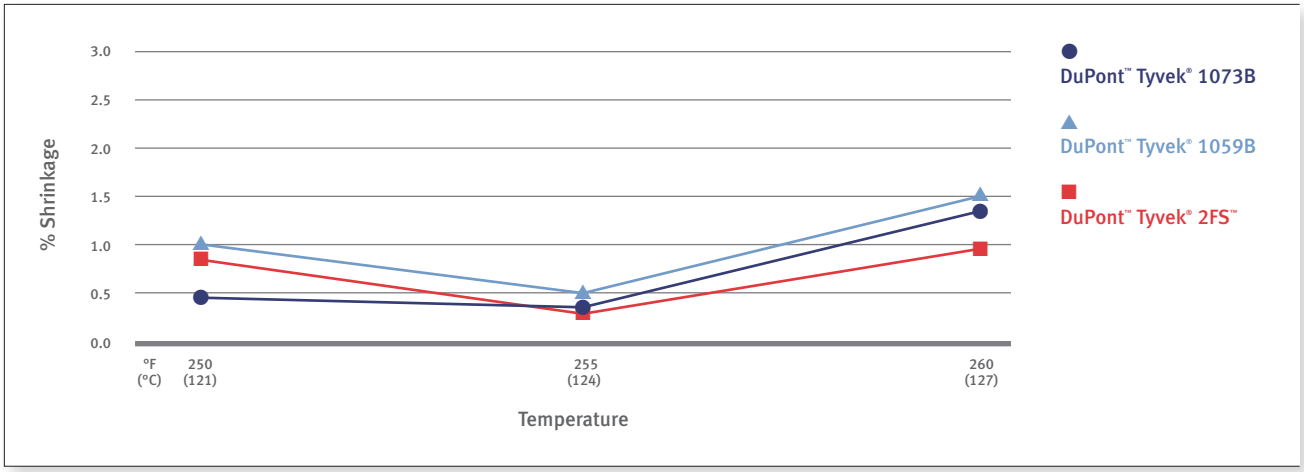


Figure 11. Results of shrinkage tests conducted on DuPont™ Tyvek® 1073B, Tyvek® 1059B and Tyvek® 2FS™ after steam sterilization.

COMPATIBILITY WITH STERILIZATION METHODS

Biocompatibility

Biological evaluation of DuPont™ Tyvek® styles for medical and pharmaceutical packaging was performed using testing methodologies according to ISO 10993 and United States Pharmacopoeia (USP). These styles meet all the acceptable performance criteria.

This testing was also performed on samples of Tyvek® after exposure to sterilization by EO, gamma and electron-beam sterilization processes and proved that Tyvek® meets all the acceptable performance criteria (Table VI) after sterilization. The results of the testing indicate biocompatibility—even after sterilization.

Table VI. Sample toxicological results for DuPont™ Tyvek® 1073B, Tyvek® 1059B and Tyvek® 2FS™

Test Performed	Unexposed	Ethylene Oxide (EO)	Gamma Irradiation (25 kGy & 50 kGy)	Electron-beam (25 kGy & 50 kGy)	STERRAD®
Determination of Extractives from Olefin Polymers[1]	Below maximum allowable percentage				
Hemolysis-Rabbit Blood-ISO[2,3]	Non-hemolytic				
L929 MEM Elution Test-USP[4]	Non-cytotoxic				
ISO-Rabbit Pyrogen Test (Material Mediated)[2,5]	Non-pyrogenic				
Kligman Maximization Test-ISO (CSO and NaCl extracts)[2,6]	Non-allergenic				
Systemic Injection Test-ISO[2,5]	No biological reaction				
Primary Skin Irritation Test-ISO[6]	Non-irritant				
Short Term Intramuscular Implantation Test-ISO (14 and 28 days)[7,8]	Non-irritant				
USP Class VI Test[9]	0% sensitization				

Tests were based on the following references:
1. 21 CFR 177. 1520, Olefin Polymers, Federal Register, Title 21, Chapter 1, 1997.
2. Biological Evaluation of Medical Devices-Part 12: Sample Preparation and Reference Materials, EN/ISO 10993-12, 1997.
3. Biological Evaluation of Medical Devices-Part 4: Selection of Tests for Interactions with Blood, ISO 10993-4, 1992.
4. United States Pharmacopoeia 25, National Formulary 20, 2002, ‹87› Biological Reactivity Tests, In Vitro.
5. Biological Evaluation of Medical Devices-Part 11: Tests for Systemic Toxicity, EN/ISO 10993-1995.
6. Biological Evaluation of Medical Devices-Part 10: Tests for Irritation and Sensitization, EN/ISO 10993-10, 1996.
7. Biological Evaluation of Medical Devices-Part 6: Tests for Local Effects After Implantation, ISO 10993-6, 1995.
8. ASTM Section 13, Volume 13.01 Medical Devices, Designation: F 981-93, 1994.
9. United States Pharmacopoeia 25, National Formulary 20, 2002, ‹88› Biological Reactivity Tests, In Vivo.

PERFORMANCE OF DUPONT™ TYVEK® AFTER AGING

DuPont™ Tyvek® inherently resists penetration by microorganisms better than other porous packaging materials because of its unique structure. Tyvek® is a sheet structure formed from continuous strands of very fine, interconnected filaments of high-density polyethylene (HDPE).

These filaments are randomly oriented and bonded together by heat and pressure. This structure also imparts other important properties for medical packaging, including: strength; resistance to penetration by water; low linting; puncture resistance; and air permeability.

Tyvek® can provide long-term sterility maintenance of sterilized and packaged medical devices. The effectiveness of Tyvek® in keeping medical devices sterile during storage has been conclusively demonstrated both by aging studies and by all of the medical devices in the market with five-year—or longer—expiry dates.

Test methods used to evaluate the microbial barrier properties of Tyvek® include ASTM F2638, ASTM F1608, DuPont Bacterial Test Chamber and others. Results from both material-based and whole-package shelf-life studies show:

- Tyvek® holds out bacterial spores, even under the most rigorous conditions.
- Bacteriological studies clearly prove the outstanding efficacy of Tyvek® as a bacterial barrier, even after repeated challenges.
- Tyvek® maintains sterility even after five years of exposure to environments contaminated with microorganisms.

The first DuPont shelf-life studies of Tyvek® were initiated in 1972 and demonstrated that Tyvek® resisted spore penetration for at least one year under normal conditions.

To extend that investigation, DuPont initiated a long-term shelf-life study of Tyvek® 1073B and Tyvek® 1059B in 1978. The study was conducted at the DuPont Haskell Laboratory for Toxicology. The objective of this program was to see how well these styles of Tyvek® would resist penetration by airborne bacterial spores. This test was designed to have a more severe microbial challenge than typical real-world conditions. The samples were challenged repeatedly with high bio-contamination levels (at ambient temperature and pressure) for months and years at a time.

The results of this study showed that Tyvek® is a remarkably reliable microbial barrier. Tyvek® can maintain sterility for at least five years, providing package integrity is maintained.

Summary of the five-year shelf-life test protocol

1. Contents of packages tested for initial sterility

Open petri dishes were sealed in special packages, 4.25 in. × 6.75 in. (10.8 cm × 17.1 cm), designed to simulate actual disposable medical devices sealed in packages. The package and contents were then sterilized using ethylene oxide (EO). Each package consisted of a lid of Tyvek® sealed to poly-PET film.

To ensure that the petri dish was sterile prior to long-term shelf storage, samples were randomly tested following the United States Pharmacopoeia (USP) methods for both anaerobic and aerobic bacteria. An anaerobic chamber was used to test for anaerobic microbial contamination. The petri dish was removed from the opened package and placed in a sterile bag containing either fluid thioglycolate culture medium or soybean casein digest broth. This tested the sterility of the packaged "device" before the multi-year shelf-life study was started.

2. Stored packages heavily dosed with bacterial spores

Packages containing sterile petri dishes were stored on shelves in cabinets protected from outside contamination and stored under controlled temperature and relative humidity. Every four months throughout the entire five years of testing, each package was sprayed with a uniform, massive dose of *Bacillus circulans* spores. Actual counts indicated 4,000 to 5,000 spores on each package.

3. Package sterility checked periodically

To check sterility, 10 packages were withdrawn randomly from the storage shelves every six months and the outside surface of the poly-Mylar® was disinfected. A small hole was then made through the poly-Mylar® film and the petri dish with a hot, pencil-tip soldering iron. Then, 15 mL of sterile nutrient agar were injected into the petri dish and the entry hole was covered with biocidal tape. If any spores had penetrated the lid of Tyvek®, they would have grown on the culture medium after incubation. No spores were detected on any samples during the study.

PERFORMANCE OF DUPONT™ TYVEK® AFTER AGING

4. Tyvek® is inspected for possible bacteria growth

The final part of the test procedure determined that the packages were indeed challenged with the bacterial spores on the outside of the lid of DuPont™ Tyvek®. A small swatch of Tyvek® from the package lid was cut out and placed on an agar medium. After evidence of bacteria growth, the swatches were examined under a microscope and colonies of *B. circulans* were counted. This acted as a check for the number of viable spores that were actually on the surface of Tyvek®. It also ensured that the density of spores was consistently maintained over the many years of the test.

Physical properties after aging

Tyvek® retains its physical properties over time, allowing a package to maintain integrity. The data shown in Tables VII through XII are for uncoated samples of Tyvek®. It is important to note that any downstream operations, such as coatings applied by sterile packaging manufacturers (SPMs), may affect the properties.

Table VII shows the physical properties before and after five-year real-time aging of Tyvek® 1073B and Tyvek® 1059B sterilized by ethylene oxide (EO). Tyvek® 1073B is the reference product providing the highest level of protection for all demanding applications and Tyvek® 1059B is the product providing robust protection for medium-risk applications.

Table VII. Physical properties of DuPont™ Tyvek® sterilized by ethylene oxide (EO) before and after five-year real-time aging

			DuPont™ Tyvek® 1073B		DuPont™ Tyvek® 1059B	
Property	Test Method	Units	Initial	After 5 Years	Initial	After 5 Years
Delamination	ASTM D2724	lbf/in. (N/2.54 cm)	0.47 (2)	0.44 (2)	0.45 (2)	0.49 (2)
Gurley Hill Porosity	TAPPI T460 ISO 5636-5	sec/100 cc	37	37	30	28
Microbial Barrier	Internal DuPont	Log Reduction Value (LRV)	5.2[1]	unchanged	4.7[1]	unchanged
Hydrostatic Head	AATCC TM 127 EN 20811[2]	in. H_2O (cm H_2O)	59+ (150+)	59+ (150+)	59+ (150+)	59+ (150+)
Tensile Strength, MD	ASTM D5035[3] EN ISO 1924-2[3]	lbf/in. (N/2.54 cm)	44.0 (196)	45.1 (201)	36.7 (163)	35.9 (160)
Seal Strength	[4]	lbf/in. (N/2.54 cm)	1.53 (7)	1.57 (7)	1.33 (6)	1.44 (6)

1. Typical values. ASTM F1608 Standard did not exist so barrier was tested by internal DuPont method similar to the current Standard. Property remained unchanged after five years.
2. Rate of use: 60 cm H_2O/min.
3. Modified for speed and gauge length.
4. Sealing conditions: temperature—290°F (143°C); dwell time—1 second; pressure (seal through the film)—90 psi (621 kPa).

PERFORMANCE OF DUPONT™ TYVEK® AFTER AGING

Accelerated aging test protocol

Samples of DuPont™ Tyvek® 1073B and Tyvek® 1059B were aged using the accelerated conditions listed below. Samples were rotated through the following cycle six times, which is equivalent to six years of aging.

- Two weeks at 130°F (54°C) with a relative humidity equal to 17%
- Two days at -4°F (-20°C)
- Two weeks at 130°F (54°C) with a relative humidity between 70% and 80%

After the accelerated aging, the samples were stored for five years at ambient temperature and humidity. These conditions were chosen before the publication of ASTM F1980-07. The results of these tests are shown in Table VIII.

Table VIII. Accelerated aging test results for DuPont™ Tyvek® 1073B and Tyvek® 1059B

			DuPont™ Tyvek® 1073B			DuPont™ Tyvek® 1059B		
				After			After	
Property	Test Method	Units	Initial	6 Cycles	5 Years	Initial	6 Cycles	5 Years
Tensile Strength, MD	ASTM D5035[1] EN ISO 1924-2[1]	lbf/in. (N/2.54 cm)	42 (187)	42 (187)	40 (178)	37 (165)	39 (174)	39 (174)

1. Modified for speed and gauge length.

Tyvek® 2FS™, a product that provides excellent protection for form-fill-seal and less-demanding applications, was introduced after the accelerated aging tests were conducted on Tyvek® 1073B and Tyvek® 1059B. The accelerated aging test conducted on Tyvek® 2FS™ was done according to industry norms at that time. In this study, samples of Tyvek® 2FS™ were aged for 36.5 weeks at 138°F (55°C) and 75% relative humidity. The results of this test are shown in Table IX.

Table IX. Accelerated aging test results for DuPont™ Tyvek® 2FS™

			DuPont™ Tyvek® 2FS™	
Property	Test Method	Units	Initial	After 36.5 Weeks
Tensile Strength, MD	ASTM D5035[1] EN ISO 1924-2[1]	lbf/in. (N/2.54 cm)	30.8 (137)	30.8 (137)
Elongation, MD	ASTM D5035[1] EN ISO 1924-2[1]	%	17	17
Microbial Barrier	ASTM F1608	Log Reduction Value (LRV)	3.1	unchanged

1. Modified for speed and gauge length.

PERFORMANCE OF DUPONT™ TYVEK® AFTER AGING

Real-time aging test protocol

Samples of DuPont™ Tyvek® 1073B and Tyvek® 1059B were sterilized using gamma and electron-beam and then aged at room temperature for seven years. Both tensile strength and microbial barrier were tested before and after aging.

Original properties prior to sterilization are shown to demonstrate the radiation stability of Tyvek®. Polymers that are not radiation stable are subject to chain scission reactions, which greatly reduce physical properties.

Table X. Real-time aging test results for DuPont™ Tyvek® 1073B and Tyvek® 1059B (metric units)

	Tensile Strength[1], N/2.54 cm		Microbial Barrier, LRV[2]
	MD	CD	
Gamma Radiation 50 kGy*			
Tyvek® 1073B			
Original[3]	187	213	5.2[4]
Initial	147	175	—
After 7 years	142	148	5.2
Tyvek® 1059B			
Original[3]	163	178	4.7[4]
Initial	122	138	—
After 7 years	118	127	4.1
Gamma Radiation 100 kGy*			
Tyvek® 1073B			
Original[3]	187	213	5.2[4]
After 7 years	103	130	5.1
Tyvek® 1059B			
Original[3]	163	178	4.7[4]
After 7 years	85	99	4.2
Electron-beam Radiation 50 kGy*			
Tyvek® 1073B			
Original[3]	187	213	5.2[4]
Initial	164	157	—
After 7 years	159	145	5.2
Tyvek® 1059B			
Original[3]	163	178	4.7[4]
Initial	143	145	—
After 7 years	135	124	4.9
Electron-beam Radiation 100 kGy*			
Tyvek® 1073B			
Original[3]	187	213	5.2[4]
Initial	120	120	—
After 7 years	96	113	5.2
Tyvek® 1059B			
Original[3]	163	178	4.7[4]
Initial	106	121	—
After 7 years	94	93	4.3

*50 kGy was a single dose; 100 kGy was a cumulative amount, representing a double dose of 50 kGy.

1. ASTM D5035 and EN ISO 1924-2; modified for speed and gauge length.
2. Log Reduction Value (LRV) as tested per ASTM F1608. Note that ASTM F1608 Standard did not exist when the test was initiated, so barrier for the original value was tested by an internal DuPont method similar to the current Standard.
3. Prior to sterilization.
4. Typical values. ASTM F1608 was not available in 1990 when the test was initiated.

PERFORMANCE OF DUPONT™ TYVEK® AFTER AGING

Table XI. Real-time aging test results for DuPont™ Tyvek® 1073B and Tyvek® 1059B (English units)

	Tensile Strength[1], lbf/in.		Microbial Barrier, LRV[2]
	MD	CD	
Gamma Radiation 50 kGy*			
Tyvek® 1073B			
Original[3]	42	48	5.2[4]
Initial	33	39	—
After 7 years	32	33	5.2
Tyvek® 1059B			
Original[3]	37	40	4.7[4]
Initial	28	31	—
After 7 years	27	29	4.1
Gamma Radiation 100 kGy*			
Tyvek® 1073B			
Original[3]	42	48	5.2[4]
After 7 years	23	29	5.1
Tyvek® 1059B			
Original[3]	37	40	4.7[4]
After 7 years	19	22	4.2
Electron-beam Radiation 50 kGy*			
Tyvek® 1073B			
Original[3]	42	48	5.2[4]
Initial	37	35	—
After 7 years	36	33	5.2
Tyvek® 1059B			
Original[3]	37	40	4.7[4]
Initial	32	33	—
After 7 years	30	28	4.9
Electron-beam Radiation 100 kGy*			
Tyvek® 1073B			
Original[3]	42	48	5.2[4]
Initial	27	27	—
After 7 years	22	25	5.2
Tyvek® 1059B			
Original[3]	37	40	4.7[4]
Initial	24	27	—
After 7 years	21	21	4.3

*50 kGy was a single dose; 100 kGy was a cumulative amount, representing a double dose of 50 kGy.

1. ASTM D5035 and EN ISO 1924-2; modified for speed and gauge length.
2. Log Reduction Value (LRV) as tested per ASTM F1608. Note that ASTM F1608 Standard did not exist when the test was initiated, so barrier for the original value was tested by an internal DuPont method similar to the current Standard.
3. Prior to sterilization.
4. Typical values. ASTM F1608 was not available in 1990 when the test was initiated.

PERFORMANCE OF DUPONT™ TYVEK® AFTER AGING

Accelerated and real-time aging test after gamma sterilization

The effect of gamma sterilization and aging on seal strength is negligible (Table XII). Pouches of DuPont™ Tyvek® 1073B and 2.5-mil polyester/polyethylene were gamma irradiated (30 kGy) and then stored at 131°F (55°C) and ambient relative humidity for a period of 10 weeks, followed by storage at ambient conditions for five years and then assessed for seal strength according to ASTM F88.

Table XII. Seal strength of DuPont™ Tyvek® 1073B after gamma sterilization following accelerated and real-time aging

		Seal Strength, lbf/in. (N/2.54 cm)
Original		0.915 (4.07)
Sterilized with 30 kGy Gamma		0.949 (4.22)
Accelerated Aging	2 weeks	0.931 (4.14)
	4 weeks	0.856 (3.85)
	6 weeks	0.953 (4.24)
	8 weeks	0.887 (3.95)
	10 weeks	0.848 (3.77)
Real-Time Aging	3 years	0.778 (3.46)

GUIDELINES FOR PRINTING ON DUPONT™ TYVEK®

Styles of DuPont™ Tyvek® for medical and pharmaceutical packaging can be printed using standard commercial printing equipment and suitable inks. Because of the unique requirements for medical and pharmaceutical packaging, these styles have no antistatic coating and are not corona treated. Therefore, special steps must be taken to obtain optimum printing results. When printing on Tyvek® medical and pharmaceutical packaging styles, we recommend testing before proceeding with production operations.

For additional information about printing on Tyvek®, refer to the *DuPont™ Tyvek® Users Manual* at www.graphics.dupont.com.

Flexographic printing guidelines

Flexography is the recommended technique for printing on Tyvek® medical and pharmaceutical packaging styles. For best results, use the smooth side of the sheet. The difference between the rough ("wire") side and the smooth side is minor, but can usually be felt. Rolls supplied directly from DuPont are wound smooth side out. Rolls supplied from a sterile packaging manufacturer (SPM) may be wound differently. Be sure to check with your SPM or supplier to determine how your rolls are wound.

With Tyvek® 2FS™, it is more difficult to feel the difference between the two sides. To help you determine the rough from the smooth side, a simple six-step procedure has been developed. For details, refer to Section 7, "Processing/ Troubleshooting Guidelines." Other important recommendations are listed here.

Press conditions for flexography

Ensuring optimum press conditions will help prevent sheet distortion, registration problems in multi-color work, softening of adhesives and ink pick-off.

- *Tensions*—Keep tensions below 0.75 lb/in. (1.3 N/cm) of width.
- *Temperatures*—Maintain web temperatures below 175°F (79°C).
- *Chilled rolls*—Use chilled rolls before windup.

Printing plates for flexography

Selecting the appropriate type of printing plate is dependent upon the nature of the printing job. General printing best practices should be followed to optimize the conditions of the pressroom for ultimate performance. Printing variables include the plate, cushion, ink and anilox. As always, it is best to clean the printing plate with 100% alcohol prior to inking to enhance ink transfer.

For printing solids, type and other fine detail-oriented images, it is best to use a medium durometer plate. This should be complemented with a medium or firm density cushion. Anilox selection should be based on a line screen and volume that does not over-ink the plate. Please seek ink manufacturer's guidelines for viscosity, pH and other transfer properties that are dependent on your ink application and resistance properties.

- Digital Solvent—use DuPont™ Cyrel® DSP or Cyrel® DPL
- Digital FAST—use Cyrel® DFP or Cyrel® DFM
- Analog—use Cyrel® NOWS or Cyrel® EXL

For images that include fine line screens with dots, it is best to use a harder durometer plate. This should be complemented with a soft or medium density cushion. Anilox selection should be based on a line screen volume that does not over-ink the plate. Please see manufacturer's guidelines for viscosity, pH and other transfer properties that are dependent on your ink application and resistance properties.

- Digital Solvent—use DuPont™ Cyrel® DSP or Cyrel® DPR
- Digital FAST—use Cyrel® DFP or Cyrel® DFR
- Analog—use Cyrel® NOWS or Cyrel® EXL

Inks for flexography

It is important to not only choose the proper ink for the process, but to verify the suitability of the ink in applications where direct contact with the medical device is likely.

- *Alcohol-based polyamide inks*—These solvent-based inks typically provide the best adhesion and rub resistance. Adding microcystalline wax will reduce the offsetting.
- *Water-based inks*—These inks make it possible to achieve high-quality results while complying with environmental regulations.

GUIDELINES FOR PRINTING ON DUPONT™ TYVEK®

Lithographic printing guidelines

Although flexography is the recommended method for printing on DuPont™ Tyvek® medical and pharmaceutical packaging styles, offset lithography can produce acceptable print quality. For best results, use the smooth side of the sheet. Although either side prints well, the smooth side is preferred because it makes sheet feeding slightly easier. The difference between the rough ("wire") side and the smooth side is minor, but can usually be felt.

Rolls supplied directly from DuPont are wound smooth side out. Rolls supplied from a sterile packaging manufacturer (SPM) may be wound differently. Be sure to check with your SPM or supplier to determine how your rolls are wound.

With Tyvek® 2FS™, it is more difficult to feel the difference between the two sides. To help you determine the rough from the smooth side, a simple procedure has been developed. For details, refer to Section 7, "Processing/Troubleshooting Guidelines." Other important recommendations are listed here.

Offset blankets for lithography

Selecting the appropriate type of blanket to use will depend on whether or not the Tyvek® is coated.

- *For adhesive-coated Tyvek®*—Use conventional offset blankets of medium hardness.
- *For uncoated Tyvek®*—Use compressible offset blankets.

Squeeze recommendation for lithography

Applying an additional 3 mil to 4 mil (0.08 mm to 0.10 mm) of squeeze between the blanket and back cylinder is required compared to that used for paper of equivalent average thickness. This additional impression, coupled with the compressibility of Tyvek®, compensates for possible thickness variations of Tyvek®.

Inks for lithography

It is important to not only choose the proper ink for the process, but to verify the suitability of the ink in applications where direct contact with the medical device is likely. In addition, follow these specific recommendations for printing on Tyvek® medical and pharmaceutical packaging styles.

- *Low-solvent-content inks*—Use inks with <3% volatile solvent because hydrocarbon solvents found in many litho inks tend to swell and distort Tyvek®. These inks also release fewer volatile organic compounds (VOCs) compared to traditional offset inks, reducing the environmental impact.
- *Extra-strong colors*—Use extra-strong colors to keep ink film thickness to a minimum (<0.3 mil [0.008 mm]). This will help minimize sheet distortion and dot gain.
- *Tint creation*—Use opaque white rather than an extender when creating tints to minimize the appearance of fiber swirl.
- *Fountain solution*—Maintain fountain solution at a minimum level. Either conventional water or alcohol/water dampening systems can be used. Alcohol substitutes also work well. Do not increase the ink volume if your images appear dull or washed out. Instead, reduce the amount of dampening solution in the fountain.
- *Drying*—Litho inks dry more slowly on Tyvek® than they do on paper, so be sure that pile height does not exceed 20 in. (0.5 m). Winding the sheets and maintaining the fountain solution at a pH between 4 and 5 can accelerate drying.

A list of ink manufacturers familiar with the unique requirements of printing on Tyvek® medical and pharmaceutical packaging styles can be obtained by contacting your regional DuPont representative.

Special notes for adhesive-coated Tyvek®

When selecting offset inks, it is important to advise the ink supplier if the Tyvek® has an adhesive coating because special ink formulations may be required to prevent ink set-off to the coated surface. In some cases, printing is done on the adhesive side. This also should be discussed with the ink supplier to ensure optimum compatibility between the ink and the coating.

GUIDELINES FOR PRINTING ON DUPONT™ TYVEK®

Variable information printing

The need to print variable information on packages has resulted in an increased use of electronically controlled printing processes. These electronic devices can output variable information such as: lot, production date, sequential numbering, product codes and bar codes. DuPont™ Tyvek® medical and pharmaceutical packaging styles are compatible with some of these processes.

Thermal transfer printing

The most common process for printing variable information is thermal transfer. This process uses heated pins to activate a pigmented wax, resin or wax/resin blend that is carried on a ribbon. The image is created when the molten ink transfers to the substrate.

Wax ribbons give the best results for Tyvek® medical and pharmaceutical packaging styles (which are not corona treated). The image durability is marginal. If more durability is required, a wax/resin blend ribbon should be used. A 90/10 wax/resin blend ribbon yields good results. This blend ribbon may need to be custom manufactured because many ribbon manufacturers only stock 50/50 blend ribbons.

Excellent results in printing alpha-numeric information have been achieved using 300- to 600-dpi printers. Because of the inherent thickness variability of Tyvek®, thermal transfer printing on Tyvek® tends to produce D-C ANSI bar code quality. If a high-density bar code is needed, or a higher-quality bar-code rating is specified, a label should be used.

Ink jet printing

Tyvek® medical and pharmaceutical packaging styles have been printed successfully using continuous and drop-on-demand ink jet printers. However, because Tyvek® is made of high-density polyethylene (HDPE) and does not absorb moisture, solvent-based inks must be used. Most water-based inks are slower drying and tend to feather on Tyvek®, resulting in a blurry image. Acceptable results have also been achieved with ultraviolet (UV) and change-of-phase inks, which cure almost instantly. Typically, 200- to 300-dpi print heads are used.

Laser (electrostatic) printing

Conventional laser printing is not recommended for Tyvek® because the high temperatures used to set the toner distort the Tyvek® during normal printing and will melt the Tyvek® if a jam occurs. Cool-process (flash-fusion) laser printers are compatible with Tyvek®; however, the toner transfer efficiency is marginal and the printed image is not as sharp as it is with thermal transfer or ink jet printers.

PROCESSING/TROUBLESHOOTING GUIDELINES

Heat sealing guidelines

The resultant material bond and seal strength of a heat seal packaging process depends on several factors, including: sealing dwell time, sealing temperature, sealing pressure, characteristics of the sealant and even the test method used to measure the seal strength. Seals must be strong enough to withstand the rigors of shipping and handling, yet at the same time facilitate easy access for the end-user to open the sterile package using aseptic presentation techniques. Optimizing the heat sealing process and consistently producing packages with the appropriate seal strength is of critical importance because it can have a direct impact on product efficacy and patient safety.

Sealing dwell time

Sealing dwell time refers to the time the heating elements of a packaging process (clamps, plates, bars, etc.) are in direct contact with the substrate(s). It can be either one-sided or two-sided heating. The two materials come together to form a bond or seal. It is important to understand how the equipment measures the dwell time to determine "true dwell time," which is when the webs are actually pressed together. That's because controls for heat sealing equipment vary and cycle time may or may not include travel time for the machine to engage into its final closed position. Any variation in the rates of materials reaching their seal initiation temperature, even by fractions of a second, can have a measureable effect on seal strength.

Sealing temperature

The heat sealing process, as previously described, marries two materials and creates a bond. To achieve this bond, one of the materials typically carries a surface sealant layer. The heating elements of heat seal packaging equipment are raised to a temperature high enough to either melt or activate the sealant.

The primary heat seal factors of time, temperature and pressure are interactive. A change or tweak in one typically requires a change or tweak in one or more of the other factors. A balance between time, temperature and pressure must be met to achieve the desired seal strength and visual seal transfer.

Depending on the activation temperature of the sealant, raising the temperature and lowering the dwell time or lowering the temperature and raising the dwell time could produce more consistent seals without transparentizing the DuPont™ Tyvek®. Temperatures must be high enough to activate the sealant layer, while not overheating the surface of the material and inducing extreme transparentization.

It is recommended to optimize the heat sealing process using tools such as Design of Experiments. This not only results in a heat sealing process that consistently produces acceptable seals, but also can optimize energy output and operational throughput and efficiencies.

Sealing pressure

The third key factor of heat sealing is the pressure at which the equipment brings together and holds the two materials together to form the seal. It is important to know the actual pressure the substrates are exposed to because this value is often not equivalent to the input pressure or the setpoint on the machine controls. There are many techniques to measure sealing pressure—from sensor paper to more sophisticated electronic sensor technologies. For most heat seal materials, pressure is the least significant of the three factors required to make a heat seal.

Other factors

The three main factors for heat sealing—dwell time, temperature and pressure—can produce significant variability in seal strength. However, there are other factors related to time, temperature and pressure that can also affect heat seals. Some common factors include:

- Variation in platen temperature—"hot spots" or "cold spots"
- Non-uniform heat transfer due to uneven contact or pressure caused by a warped or misaligned platen
- Material thickness or variation

To produce uniform seal strengths resulting in clean, peelable seals that are strong enough to withstand the rigors encountered during shipping, it is important to develop a robust heat sealing process by optimizing the dwell time, temperature and pressure for specific material combinations.

Avoiding fold problems

A sheet of DuPont™ Tyvek® is a monolayer material that is heat treated or bonded on both sides. This treatment makes the exterior less flexible than the interior of the structure and allows the monolayer material to perform more closely to a multilayer structure (Figure 12).

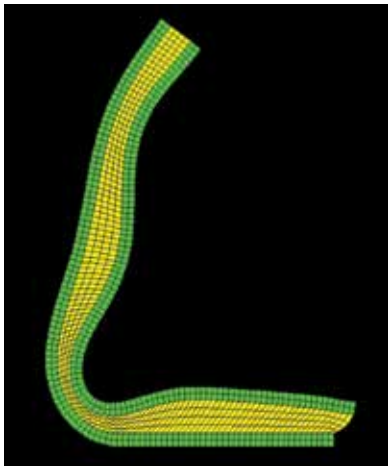


Figure 12. Pictorial representation of DuPont™ Tyvek® during package opening.

Tyvek®, a monolayer material, acts like a multilayer material represented by the green/yellow/green layers.

When any sheet structure is bent, the outer surface is placed in tension while the inner surface is placed in compression. The tighter the bend, the greater these forces become. If these loads become excessive, the filament structure holding the two layers together will succumb to the forces and the inner surface will buckle inward (Figure 13).

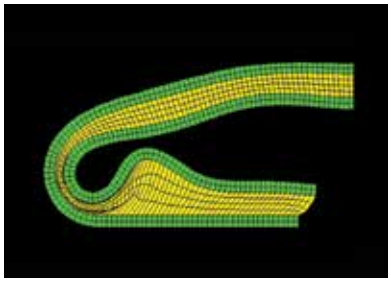


Figure 13. Pictorial representation of DuPont™ Tyvek® during opening at an extreme angle.

An extreme fold or bend puts the exterior surface in tension and the interior surface in compression, causing the interior of the sheet to buckle.

The result will be the formation of a delaminated area along the center line of the sheet of Tyvek®. This is commonly seen when the flexible edge of the pouch seal is bent or folded to fit into a shelf carton. With the pouch film on the outside of the bend, all of the force to make the fold is converted to compression loads on the inner surface of the sheet of Tyvek®, which may lead to separation within the interior of the sheet, commonly referred to as sheet separation (Figure 14). However, it has been demonstrated that this phenomenon does not compromise the integrity of the package.

Figure 14. Micrograph of folded DuPont™ Tyvek® showing sheet separation, a phenomenon that does not compromise the integrity of the package.

Specifically, samples were designed that would allow a microbial aerosol challenge to be applied to both the sheet of Tyvek® and the seal section containing the delaminated area. The samples were placed in the apparatus used in the ASTM F1608 and ASTM F2638 microbial barrier tests. No reduction in Log Reduction Values (LRV) for ASTM F1608 or percent penetration rates for ASTM F2638 was observed.

Sheet separation is typically encountered during the qualification phase of package testing. During underwater bubble leak testing (ASTM F2096:2002) a pouch with sheet separation will produce a stream of air bubbles that appear to be a channel in the seal. This result requires additional lab testing to determine if there is truly a channel in the seal or if sheet separation has produced a false positive.

PROCESSING/TROUBLESHOOTING GUIDELINES

A dye penetration test (ASTM F1929:2003) is used to differentiate a channel (Figure 15) from sheet separation. Lab technicians must follow the ASTM protocol when performing the test to ensure "wicking" is not produced.

If dye is left too long in the pouch made with DuPont™ Tyvek®, the dye begins to wick through the material (Figure 16).

Another way to confirm sheet separation vs. a channel is to reserve the pouches after dye testing, wait until the residual dye has dried and then peel the pouch open to reveal either dye in the sealed area, indicating a channel in the seal, or no dye, indicating sheet separation.

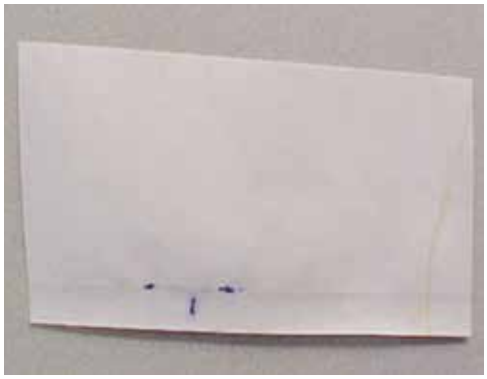


Figure 15. Channel in seal determined during dye penetration testing (ASTM F1929:2003).

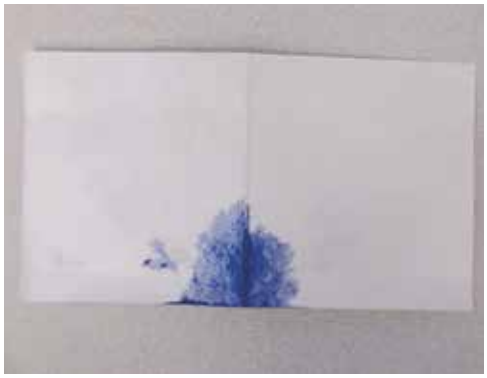


Figure 16. Wicking occurs when dye is left too long in the pouch during ASTM F1929:2003 testing.

The best way to avoid sheet separation issues and false positives is to avoid folding pouches. However, if the package fold is necessary, opt for a gentle curl instead of a true fold.

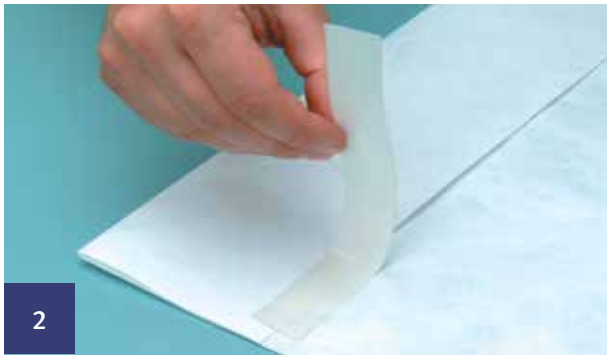
For more information, read "Porous Sterile Barrier Integrity Testing: Failure Anomalies," an article that was published in the January 2006 issue of *MD&DI* magazine. This article can be found in the magazine's online archives at www.mddionline.com.

PROCESSING/TROUBLESHOOTING GUIDELINES

Determining the rough vs. smooth side of DuPont™ Tyvek® 2FS™

When sealing to Tyvek® 2FS™, it is important to always seal to the rough side. Sealing to the smooth side will result in fiber tear/delamination. Typically, rolls of Tyvek® 2FS™ are wound smooth side out when they are shipped. However, the following steps can be used to verify which way the roll is wound.

Fold back the edge of the Tyvek® approximately 6 in. (15 cm) and crease flat. NOTE: If the roll is wound correctly with the smooth side out, the folded area will be the rough side.

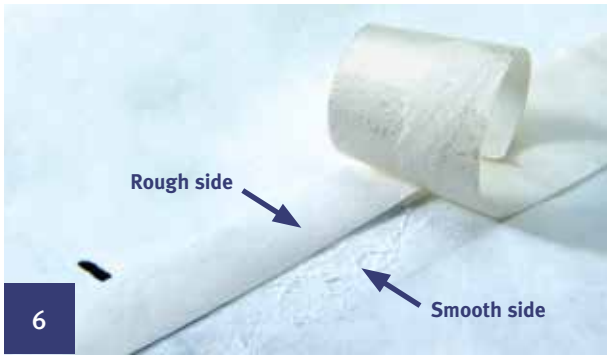


Cut a strip of 1 in. (2.5 cm) wide ARclad® AR-516 tape approximately 8 in. (20 cm) long. Place it on the "seam" so that approximately ½ in. (1 cm) is on the smooth side and ½ in. (1 cm) is on the rough side.

Smooth the tape down by running your finger along the "seam" one or two times. Use moderate pressure.

Using a felt tip pen or marker, draw a line on one side of the tape, extending the line onto the Tyvek® for easy identification.

Peel off the strip of tape.



Look at the adhesive side of the tape and note which half shows evidence of fiber tear. This will be the smooth side. NOTE: If you have any doubt, take the existing flap and fold it back on itself approximately 2 in. (5 cm) to create a new "seam." Then, repeat steps 2 through 6.

Fiber tear

Fiber tear results from a delamination of the sheet of DuPont™ Tyvek®, which is caused by a sharp bend of Tyvek® as it is being peeled from the film web. (See "Avoiding Fold Problems" on page 31 for a description of how this delamination occurs). To eliminate fiber tear, the first option is to reduce the seal strength. If this does not produce the desired result, you can consider either of the following possible solutions:

- Use a more flexible film that will not force Tyvek® to bend as much when the seal is opened. —OR—
- Use a heavier basis weight of Tyvek® that has a greater bend radius and a lower tendency to delaminate.

Cutting and slitting Tyvek®

Blades, cutting wheels and dies need to be maintained so they are sharp and free of nicks and other imperfections that could cause rough, irregular cuts. Irregular edge cuts could enable films or foils to adhere to filaments from the center region of the Tyvek® sheet during heat sealing. This attachment to individual filaments, as opposed to the bonded Tyvek® surface, could cause fiber tear and/or delamination during peeling.

Forming pouches

Tyvek® should not be sealed all the way to its edge because this could allow adhesive to flow around the edge of the bonded Tyvek® surface and attach to individual filaments. This attachment to individual filaments, as opposed to the bonded Tyvek® surface, could cause fiber tear and/or delamination during peeling.

When forming multiple pouches across the web, tooling should be designed so that an unsealed area of at least 1 mm resides between adjacent pouches. Singularizing pouches across the web should be performed in unsealed areas between pouches. Any edge trim removed from outside pouches on the web after sealing should be cut off in an unsealed area.

Sealing lids to trays

Several factors cause or greatly increase the occurrence of fiber tear when opening lids sealed to either rigid or flexible thermoformed trays. Eliminating these factors can greatly reduce the probability of fiber tear and allow for a clean peel opening.

Figure 17 demonstrates various lid placements on a tray and the predicted result after peeling. A leading cause of fiber tear is improper lid placement and/or improper lid size.

Lids should not be sealed all the way to the edge of the tray. This could allow adhesive to flow around the edge of the bonded Tyvek® surface and attach to individual filaments. This attachment to individual filaments, as opposed to the bonded Tyvek® surface, could cause fiber tear and/or delamination during peeling.

Additionally, if the edge of the lid has a microscopic nick or rough cut edge, this can act as an initiation point for a tear when the lid is peeled.

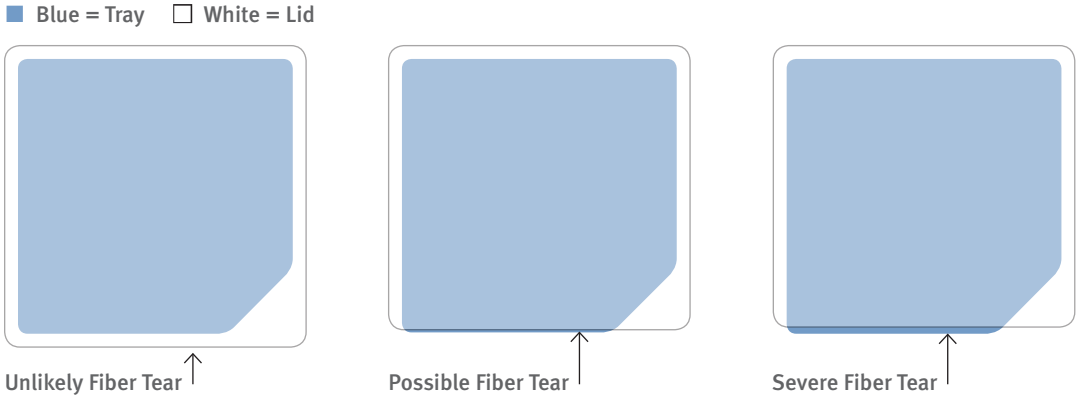


Figure 17. Prediction of fiber tear based on lid alignment on tray.

PROCESSING/TROUBLESHOOTING GUIDELINES

Tooling should be designed so that an unsealed area of at least 1 mm resides between adjacent trays, also known as a "skirt" (Figure 18), or in the case of an individual thermoformed tray, the lid overhangs the outer tray edge by at least 1 mm.

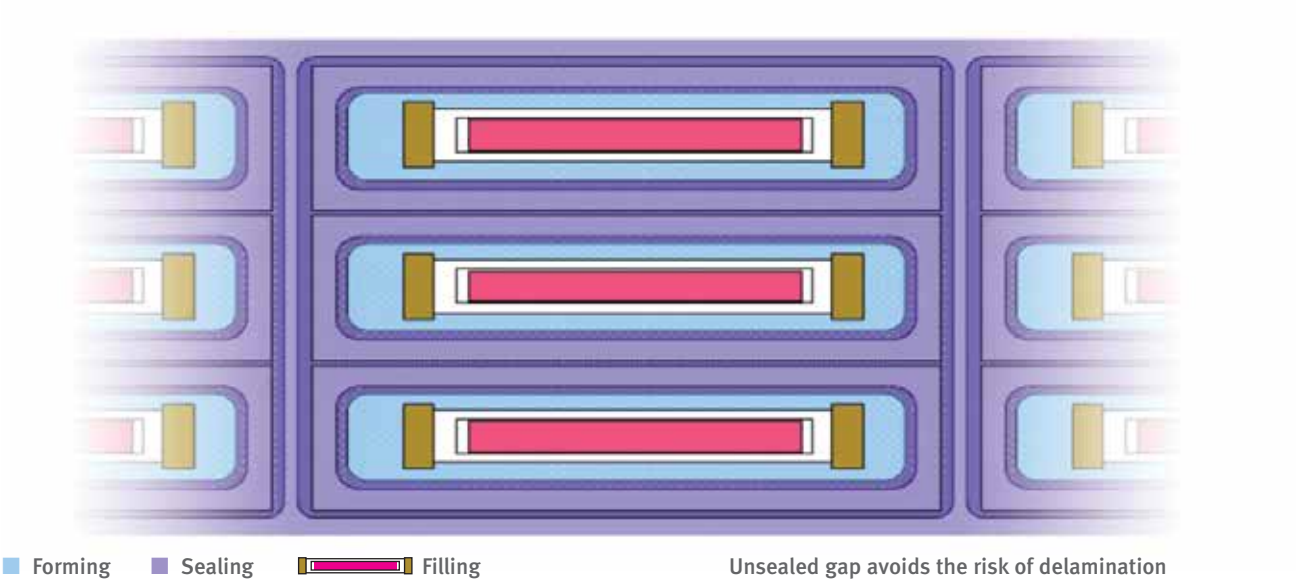


Figure 18. Multiple cavity thermoform with "skirt" seal or gap between sealed areas.

PROCESSING/TROUBLESHOOTING GUIDELINES

In an experiment conducted by DuPont, lid placement was a strong predictor of whether or not the lid would experience fiber tear during opening (Figures 19 and 20). The physics of peeling open a lid from a tray requires an adhesive break of the bond between the heat seal coating and the tray. A proper adhesive break leaves the heat seal coating on the tray (white witness mark) and allows the lid to peel cleanly away from the tray. An oversized lid allows for clean initiation of the peel.

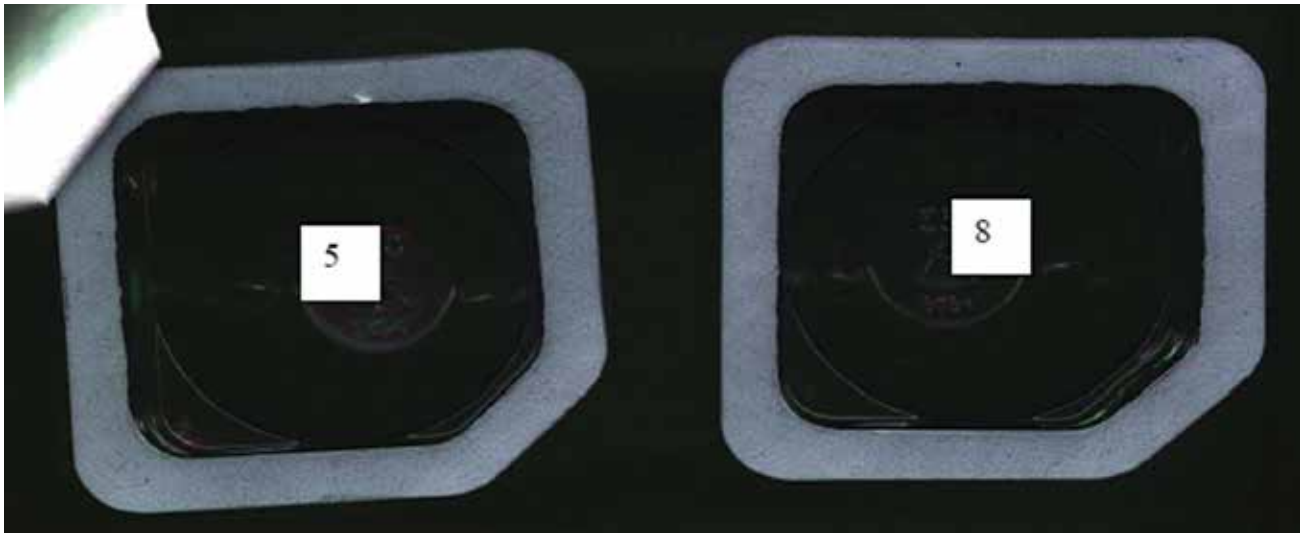


Figure 19. DuPont sealing experiment to test the effect of lid placement on fiber tear.

Proper lid placement with minimum of 1-mm lid overhang all the way around the tray.
All 32 samples showed consistent seal area and no delamination during opening.

Figure 20. Results of improper lid placement during DuPont sealing experiment.

There was no overhang; lid length and width dimensions were equal to the tray seal area dimensions.
A total of 26 out of 32 samples experienced fiber tear ranging from minimal to extreme.

METHODS FOR MEASURING PROPERTIES

DuPont uses test methods that are based upon recognized industry methodologies (Table XIII). Many of the methods developed to measure properties of porous packaging materials were developed for paper. As a result, DuPont has modified some of these methods to allow them to work with DuPont™ Tyvek®. Additionally, the use of internal methods based on those of organizations such as ASTM and ISO allows for the assessment of the impact on test results for any standardized test method modification.

Table XIII. Test methods used for measuring material properties

Property	Comparable Test Method	DuPont Test Method Number	Footnote (Deviation from Standard)
Basis Weight	ASTM D3776 EN ISO 536	0010	Modified sample size. Modified sample size.
Gurley Hill Porosity	TAPPI T460 ISO 5636-5	0034	Modified sample size. Modified for sealing fluid characteristics.
Delamination	ASTM D2724	0005	Modified for speed and gauge length.
Opacity	TAPPI T425 ISO 2471	0020	Modified for different backing standards, area and illumination.
Thickness (individual)	ASTM D1777 EN 20534, EN ISO 534	0027	7.15 psi, 0.625-in. diameter presser foot. Surface 2 cm^2, pressure 14.5 psi (100 kPa).
Tensile Strength	ASTM D5035 EN ISO 1924-2	0041	Modified for speed and gauge length. Modified for speed and gauge length.
Elmendorf Tear	ASTM D1424 EN 21974	0007	
Hydrostatic Head	AATCC TM 127 EN 20811	0056	Rate of use: 60 cm H_2O/min.
Mullen Burst	ASTM D774 ISO 2758	0014	
Bendtsen Air Permeability	ISO 5636-3	—	
Elongation	ASTM D5035 EN ISO 1924-2	0041	Modified for speed and gauge length. Modified for speed and gauge length.
Spencer Puncture	ASTM D3420	1268	Modified for $^9/_{16}$-in. (14.28-mm) probe.

A1

METHODS FOR MEASURING PROPERTIES

Basis weight

The measure of the weight per unit of area of the sheet. This is typically expressed in oz/yd^2, g/m^2, or lb/3,000 ft^2 ream. For example, DuPont™ Tyvek® 1073B has a basis weight of 2.20 oz/yd^2, 74.6 g/m^2 or 45.8 lb/ream. *Reference standards: ASTM D3776 and EN ISO 536 (both modified sample size).*

Coefficient of friction

The measure of how slippery the surfaces of a substrate are relative to itself or to some other surface, typically wood or metal. Tyvek® has a low coefficient of friction. This means that sheets of Tyvek® slide easily over one another and on other surfaces. This is important when reams of cut sheets are moved because a sudden stop or turn can cause the stack to slide and the ream to collapse. It is also critical when processing Tyvek® on a form-fill-seal (FFS) machine. DuPont does not typically measure the coefficient of friction of Tyvek®. For spot checks, we have used a slide angle instrument to measure the angle at which a sample with a 1-lb (0.45-kg) weight will start sliding. For Tyvek®, this is approximately 18 to 20 degrees. Paper has a 30-degree slide angle.

Delamination

The measure of the internal bonding level of a given substrate. It is the weakest point of any substrate, which is almost exactly in the middle for Tyvek®. To perform the measurement, a split is initiated in a 1-in. (2.5-cm) wide sample. This split is the starting point to peel the layers apart. The average force to continue the peel is measured using a tensile tester. The results are given as lb$f$/in. or N/2.54 cm. Tyvek® medical and pharmaceutical packaging styles are among the most highly bonded styles of Tyvek®. This property is very important for process control of medical packaging. *Reference standard: ASTM D2724 (modified for speed and gauge length).*

Elongation

The measure of the extent a substrate will stretch before it breaks. The units are percentage (%) of sample length. Thus, a 10-in. (25-cm) sample of a substrate that has 20% elongation will stretch 2 in. (5 cm) before breaking. Two aspects of elongation are important: one is the total elongation, which relates to how much energy the substrate can absorb (i.e., resiliency); and the other is the initial slope of the stress-strain curve, which relates to how rapidly the substrate elongates when initial forces are applied. This property is referred to as the initial modulus of the material. Both are important in medical packaging because the first relates to the protective nature of the material and the second relates to how a package distorts as pressures are applied. In web-fed equipment, the initial modulus also relates to how much the material resists loss of registration. Elongation is measured by taking a 1-in. × 8-in. (2.5-cm × 20-cm) strip of product, clamping it so that 5 in. to 6 in. (13 cm to 15 cm) are between the jaws of a tensile tester, and then applying force to the ends until the sample breaks. *Reference standards: ASTM D5035 and EN ISO 1924-2 (both modified for speed and gauge length).*

Hydrostatic head

The measure of the pressure required to force three drops of water through a substrate. It is converted to the height of a column of water, which corresponds to the pressure. The units are typically inches (in.) or centimeters (cm). This property is impacted by the substrate's affinity for water. For Tyvek® medical and pharmaceutical packaging styles, the surface energy is 32 dynes/cm to 25 dynes/cm. *Reference standards: AATCC TM 127 and EN 20811 (rate of use: 60 cm H_2O/min.).*

Microbial barrier

The measure of the ability of a porous substrate to prevent bacterial spore penetration. One standard test method, ASTM F1608, measures the "filtration" efficiency of a substrate to remove spores from an aerosol being forced through the substrate in an air stream.

A completely impermeable control sample (microbial penetration is zero) is challenged with one million or 10^6 colony forming units (cfu). The number of cfu 10^6 has a $\log_{10}$ value of 6. If a sample challenged in the same way as the control allows 10 cfu ($\log_{10}$ 10 = 1) to penetrate, then its log reduction value (LVR) is 5 (6 – 1 = 5). Therefore, the higher the LRV, the more resistant the packaging is to bacteria and microorganisms. Tyvek® 1073B has an LRV of 5.2 and is the best porous substrate available for medical packaging.

METHODS FOR MEASURING PROPERTIES

There are two disadvantages associated with ASTM F1608. The first is that the test method's air flow rate significantly exceeds the air flow rate seen during typical distribution of a medical device. The second disadvantage is that it takes a long time to incubate the spores to get a count of how many spores penetrated the test material.

ASTM F2638 eliminates both of these problems. It's a real-time test, eliminating the need to incubate spores. It functions by counting inert particles as they penetrate the barrier material. More importantly, the air flow rates are close to those experienced during transportation, eliminating the other disadvantage. This test method also varies the flow rate and thereby generates a penetration curve. On this penetration curve, most substrates tested have a maximum. Therefore, it is possible to report a pMax, which is the maximum penetration for the given substrate. The flow rate at which the maximum occurs depends on the mass, fiber diameter and density of the substrate.

Moisture vapor transmission rate (MVTR)

The measure of the rate at which moisture vapor is transmitted through a sample. There are several different manufacturers of MVTR equipment. It is important to note that MVTR results are highly dependent on the test method used and the material type. Important variables between test methods include: pressure gradient; volume of air space between liquid and sheet sample; temperature; air flow speed over the sample; and test procedure. Therefore, the results are not comparable from one company to another, nor between different pieces of equipment. *Reference standard: TAPPI T523 (test conditions: 73˚F [23˚C], 85% relative humidity).*

Mullen burst

The measure of the ability of a substrate to resist forces applied uniformly throughout the substrate. It is measured by clamping a sample in a ring stand and expanding a diaphragm under the sample until the sample ruptures in the weakest spot. The pressure in the diaphragm (psi or kPa) is recorded. Because DuPont™ Tyvek® is isotropic (exhibits the same value when measured along axes in all directions), it has a very high Mullen burst for a low weight material. Mullen burst is proportional to the basis weight of the material, the bonding level, and to some extent, the elongation. The Mullen burst value increases as these three property values increase. This property indicates how a package may perform in environments where pressure changes take place and the package balloons or where a force is applied over a relatively large area, such as when a heavy object is placed on top of a lidded tray. *Reference standards: ASTM D774 and ISO 2758.*

Opacity

The measure of how much light passes through a substrate. It is a ratio of the reflected light through a sample with a white and a black background. If the reflected light is the same from both backgrounds, then the opacity is 100%. A white background without any sample reflects 100% of light. A black background has zero reflectance. Opacity depends on the basis weight and bonding level of Tyvek®. Because Tyvek® medical and pharmaceutical packaging styles are highly bonded, the opacity is relatively low. Opacifiers, such as TiO_2 used in Tyvek® 2FS™, improve visual appearance and bar code readability. *Reference standards: TAPPI T425 and ISO 2471 (modified for different backing standards, area and illumination).*

Porosity

The measure of the ability of a substrate to permit flow of air at a given pressure differential. Two methods are used: Gurley Hill porosity in the United States and Bendtsen air permeability in Europe and most of the rest of the world. The Gurley Hill method measures the time to pass 100 cc of air through 1 $in.^2$ (6.45 cm^2) of sample at a pressure of approximately 5 in. (13 cm) of water. The Bendtsen method measures the actual flow rate of air in mL/min through a 10 cm^2 sample at a pressure differential of 1.5 kPa (6 in. of water). Porosity is important for gas sterilization processes to ensure that a sufficient amount of sterilant saturates the package in a short time and that the subsequent flushing and aeration of any residuals of the sterilant are efficient. Porosity also allows the packages to equilibrate rapidly from the pressure changes that occur in sterilization, shipping and storage environments. If any material in the device develops an odor after gamma radiation, the porous material allows the odor to vent so that none is evident when the package is opened. *Reference standards: Gurley Hill Porosity: TAPPI T460* (modified sample size) *and ISO 5636-5 (modified for sealing fluid characteristics); Bendtsen Air Permeability: ISO 5636-3.*

METHODS FOR MEASURING PROPERTIES

Spencer puncture

The method for determining the impact resistance of plastic films and packaging materials under conditions that closely approximate the strain rate that these materials are subject to in the healthcare industry. This property indicates how a package will perform if an object falls on the package or if an object in the package strikes the lid. DuPont uses procedure B of ASTM D3420, modified with a 9/16-in. (14.3-mm) diameter hemispheric-shaped probe tip with a 6,400-gram pendulum, which is necessary to puncture tough materials like DuPont™ Tyvek®. Results using different test apparatus are not comparable. *Reference standard: ASTM D3420 (modified for 9/16-in. [14.28-mm] probe).*

Tear

The measure of the ability of a substrate to resist tearing when a highly localized force is applied. Elmendorf tear measures the energy required to propagate an initiated tear for a unit distance. The units are lb*f* or Newtons. This property is important because nicks and cuts may occur at the edge of a lid and could affect its clean peel. The tear strength of Tyvek® is significantly higher than that of medical-grade paper. *Reference standards: ASTM D1424 and EN 21974.*

Tensile strength

The measure of the ability of a substrate to resist loads in the plane of the sheet. The units are lb*f*/in. or N/2.54 cm. Along with elongation, tensile determines the ability of a material to absorb energy before failure. Tensile is measured by taking a 1-in. × 8-in. (2.5-cm × 20-cm) strip of product, clamping it so that 6 in. (15 cm) are between the jaws of a tensile tester, and then applying force to the ends until the sample breaks. *Reference standards: ASTM D5035 and EN ISO 1924-2 (both modified for speed and gauge length).*

Thickness

The measure of the distance between the upper and lower surfaces of a substrate. The units of measure are usually mils, µm or mm. Thickness is measured by placing the material on a hard, flat surface and then determining the distance from the base by using a presser foot that is parallel to the base and applied to the top surface of the material. The presser foot is normally circular and the pressure applied to the foot depends on the material measured. For Tyvek®, the pressure is 7.15 psi and the foot diameter is 0.625 in. The measurement corresponds to the highest spot in the area covered by the presser foot. The larger the cross-sectional area of the presser foot, the greater the chance to pick the highest spots on the sheet. For this reason, the average thickness value measured for a sheet is lower as the area of the presser foot decreases. The standard deviation for thickness is approximately 1 mil (25 µm). *Reference standards: ASTM D1777 (modified to use 7.15 psi, 0.625-in. diameter presser foot,) EN 20534 (modified to use surface 2 cm^2, pressure 14.5 psi [100 kPa]) and EN ISO 534.*

DESCRIPTION OF SAMPLING PLANS

Specification Properties

The process of manufacturing DuPont™ Tyvek® requires strict adherence to good manufacturing practices, ISO 9001 protocol and quality control measures. DuPont manufactures Tyvek® medical and pharmaceutical packaging styles using statistical process control methodology to control three specification properties: basis weight, delamination (i.e., internal bond strength), and Gurley Hill porosity. These properties are controlled to a nominal value to produce material within specification ranges.

Specification properties are reported as a nominal value, a low value (minimum) and a high value (maximum), the latter two values representing the specification range within which product is released. Specification properties are reviewed periodically (and/or on an as-needed basis) and are based on process capability, market requirements and product performance history. Specification properties are based on roll averages with samples taken uniformly across the sheet. Routine sampling plans for specification properties are described here. Startup, transitions between styles of Tyvek® or abnormal situations may require additional sampling.

Sampling plans for specification properties

Basis weight, delamination and Gurley Hill porosity measurements are made off-line in the laboratory. Basis weight is also monitored continuously on-line.

Laboratory samples are taken from full-width rolls typically once or twice per 8-hour shift.

Basis weight, delamination and Gurley Hill porosity laboratory measurements are made at 12 approximately equally spaced locations across the roll; numbers are averaged to give "roll averages"—which are compared to specifications. Note that laboratory basis weight measurements may be made at frequencies less than once or twice per 8-hour shift when the process is stable—but not less than once per day.

Good laboratory practices, such as timely instrument calibration and measurement control testing, are used to generate laboratory data. The lab data is kept for up to 10 years.

Miscellaneous properties

DuPont reports miscellaneous physical, mechanical and barrier properties to demonstrate the outstanding balance of properties that Tyvek® features. These miscellaneous properties provide useful information when comparing Tyvek® to other packaging materials.

Sampling plans for miscellaneous properties

Miscellaneous properties represent typical values based on roll averages, with samples taken at locations and frequencies comparable to specification properties (unless otherwise noted). Miscellaneous properties **are not** controlled in the process and, therefore, are subject to slight changes from "normal" process drift.

Miscellaneous properties are measured in the laboratory from samples taken from full width rolls. Laboratory measurements are made at 6 to 12 approximately equally spaced locations across the roll and averaged to give "roll averages," except for thickness, where approximately 112 individual data points are taken at 1-in. (2.54-cm) intervals. These data points are pooled with individual data points from other rolls and averaged to give an individual (average) thickness.

Microbial barrier and Moisture Vapor Transmission Rates (MVTR) are not determined for each roll, but are checked approximately once per year.

Laboratory data is generated following established procedures and guidelines, which include good laboratory practices, such as timely instrument calibrations. The lab data is kept for up to 10 years.

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Information in the test method and sampling plan sections of this *DuPont Technical Reference Guide for Medical and Pharmaceutical Packaging* is valid as of October 2013. DuPont reserves the right to modify testing per our change control procedures as needed to meet customer needs or to improve production control and efficiency.

GUIDE TO SOME COMMON INDUSTRY ACRONYMS

AATCC . . . . . American Association of Textile Chemists and Colorists

AAMI . . . . . Association for the Advancement of Medical Instrumentation

ANSI . . . . . American National Standards Institute

AORN . . . . . Association of periOperative Registered Nurses

ASQ . . . . . American Society for Quality

CAMDI . . . . . China Association for Medical Device Industry

CD . . . . . Cross Direction

CEN . . . . . European Committee for Standardization

DIN . . . . . Deutsches Institut fur Normung (German standards organization)

EDANA . . . . . European Disposables and Nonwovens Association

EDMA . . . . . European Diagnostic Manufacturers Association

EN . . . . . European Norm

FDA . . . . . Food and Drug Administration

FICCI . . . . . Federation of Indian Chambers of Commerce and Industry

HPRC . . . . . Healthcare Plastics Recycling Council

IoPP . . . . . Institute of Packaging Professionals

ISO . . . . . International Organization for Standardization

ISTA . . . . . International Safe Transit Association

JAMI . . . . . Japan Association for the Advancement of Medical Instrumentation

JIS . . . . . Japanese Industrial Standards

JSA . . . . . Japanese Standards Association

LRV . . . . . Log Reduction Value

MD . . . . . Machine Direction

MDD . . . . . Medical Device Directive

MDM . . . . . Medical Device Manufacturer

MDMA . . . . . Medical Device Manufacturers Association

MEDEC . . . . . Medical Devices Canada

PDA . . . . . Parenteral Drug Association

SAC . . . . . Standardization Administration of the People's Republic of China

SAL . . . . . Sterility Assurance Level

SBA . . . . . Sterile Barrier Association (formerly ESPA, European Sterilization Packaging Association)

SEM . . . . . Scanning Electron Micrograph

SPM . . . . . Sterile Packaging Manufacturer

TAG . . . . . Technical Advisory Group

TAPPI . . . . . Technical Association of the Pulp and Paper Industry

USP . . . . . United States Pharmacopoeia

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For more information about DuPont™ Tyvek® for medical and pharmaceutical packaging and to find out how we can help you with packaging and regulatory compliance, call us today at 1.800.44.TYVEK or visit us at www.MedicalPackaging.DuPont.com.

You can also find links to other resources in your country and information in other languages at this website.

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