PDL HANDBOOK SERIES

Film Properties

of Plastics and Elastomers

A Guide to Non-Wovens in Packaging Applications

Second Edition

Liesl K. Massey

pdl
Plastics Design Library

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Library of Congress Catalog Card Number: 2003014890
ISBN: 1-884207-94-4

Published in the United States of America by
Plastics Design Library / William Andrew, Inc.
13 Eaton Avenue
Norwich, NY 13815
1-800-932-7045
www.williamandrew.com
www.knovel.com

10 9 8 7 6 5 4 3 2 1

Library of Congress Cataloging-in-Publication Data

Massey, Liesl K.
Film properties of plastics and elastomers : a guide to non-wovens in packaging applications / Liesl K. Massey.--2nd ed.
p. cm.
Includes bibliographical references and index.
ISBN 1-884207-94-4
1. Plastics. 2. Elastomers. I. Title.

TA455.P5. M3436 2003
620.1'92392--dc22

Plastics Design Library, 13 Eaton Avenue, Norwich, NY 13815 Tel: 607/337/5080 Fax: 607/337/5090

Preface

Welcome to the Second Edition of *Film Properties of Plastics and Elastomers: A Guide to Non-Wovens in Packaging Applications.* This edition presents an overview of film properties, including physical, optical, electrical, and permeation properties, as well as regulatory information where relevant to the use of different materials presented. These material chapters present the quantitative data in tabular and graphical formats accompanied by a qualitative discussion regarding the general film properties and film applications.

Film Properties of Plastics and Elastomers: A Guide to Non-Wovens in Packaging Applications, is a companion to *Permeability Properties of Plastics and Elastomers: A Guide to Packaging and Barrier Materials* (2003). These two volumes together update the single volume *Permeability and Other Film Properties of Plastics and Elastomers,* published in 1995. These books strive to serve as a comprehensive application-based reference for engineers, designers, scientists, or anyone interested in the properties of plastic and elastomeric films.

The materials presented herein represent those materials widely used in film packaging applications today. The data were gathered from many sources including material manufacturers, technical journals and papers, etc., and normalized into SI units for easy comparison. Extensive references are provided for the user who wishes to do more in-depth research. It should be noted that the content of the material chapters strives to be representative rather than all-inclusive. That is, a material's trends and characteristics are represented with as much detail as possible from the sources available. All manufacturers of all materials are not included due to obvious space limitations.

A special word of thanks to all those who allow their information and test data to be included in this reference. It is my hope that users find the format easy to use and the information relevant to their application needs. Every effort was made to present the information in its original context. As always, your feedback on improving this volume or others in the PDL Handbook series is appreciated and encouraged.

Liesl K. Massey 2003

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Introduction

This handbook is designed to be a reference providing information on film properties of the most commonly used packaging materials. Each material chapter presents information and data on the material and its use and performance characteristics when used as a packaging film. Chapters for different materials of the same family are grouped together(e.g., polyamides [nylons] are represented by Chs. 10–17). Comprehensive references are presented for further study.

The term "packaging" has come to mean so much more than a brown or waxed paper bag used to carry food and other store bought items. The benefits of today's packaging technology can be seen in many different industries and applications: not just in the well known food and medical applications, but also in the building and transport industries, in electricity and electronics, and in textiles and fibers.

Modern packaging films must protect the contents against contamination and spoilage, and be aesthetically pleasing as well as convey important safety or nutritional information to the purchaser, all the while being light in weight but strong and easy to transport and handle. It's no wonder plastics fit the role so perfectly.

There is a popular saying: "Packaging not only protects the contents, it protects the consumer." Packaging film provides protection against oxidation, heat, microbes, etc., can resist humidity and ultraviolet light, and can allow undesirable gases to escape, maintaining the preferred environment for the contents. Covering fresh produce even with "normal" plastic films prolongs its life by several days.[1168]

Plastic packaging has contributed in several ways to improved quality of life through enhancements in medical and pharmaceutical packing, through tamper-proof closures, hermetically-sealed packages, and longer shelf-life for medicines.

All these wonderful attributes are enhanced due to the excellent economics of plastic packaging. They are inexpensive to produce, light in weight and bulk, important for shipping, can be flexible or rigid, and can take almost any shape. Plastics for packaging use a mere 2% of oil consumption; plastic production in total consumes only 4%.[1168]

Much of today's plastic packaging market consists of multilayered films and sheets. Combining multiple layers of plastics with different material properties allows a film to be tailor-made for a specific application, combining the properties of each layer to further enhance the packaging. This allows for technical as well as economic advantages, since an expensive material may be used in just the thickness required to impart its property (for example, as an oxygen barrier); less expensive materials may serve as a thicker base providing necessary strength characteristics.

Multilayer films are generally extruded simultaneously through a single die. Adhesive polymers are often used as tie layers to join materials that do not exhibit strong adhesion to each other.

Packaging films are generally between 0.250 and 0.125 mm in thickness; the heavier gauge materials often used for blister packaging are referred to as sheet. Films must be thick enough to be self-supporting, but thin enough to be flexed, folded, or creased without cracking.[1171]

1.0 Packaging Materials

Materials for packaging fall into one of two categories: commodity films and specialty films. Commodity films include low density polyethylene (LDPE), high density polyethylene (HDPE), and polyvinylchloride (PVC). Specialty films are often higher priced and coated or coextruded for superior performance.

Types of Specialty Films:[1171]

- Oriented films, including oriented polyester (OPET), oriented polypropylene (OPP), oriented nylon (ON), and oriented polystyrene, (OPS)
- Cellophane
- Polyvinylidene chloride (PVDC)

Material Properties of Specialty Films:[1171]

- Ability to maintain integrity under extreme temperature conditions (e.g., from freezer to boiler)
- Electrical properties: insulating or conducting
- Good strength, durability, and other mechanical properties

1.1 Uses of Packaging Materials

This section presents a summary of packaging materials and some of their uses.

Cellophane:[1171]

- Often coated with PVDC to provide heat-sealablity and to create an oxygen barrier
- Used where stiffness and dead fold is required
- Advantages: transparency, folding properties, stiffness, machinability
- Disadvantages: poor moisture barrier, which contributes to poor dimensional stability when affected by moisture

Nylon:[1171]

- Often used as the base film when coated with LDPE, ethylene vinyl alcohol copolymer (EVOH), and PVDC, and where a durable oxygen barrier is required
- Advantages: low temperature durability and thermal stability; excellent oxygen and flavor barrier
- Disadvantages: high price, poor moisture barrier

Polyester:[1171]

- Used as a laminate for vacuum processing and as a high-strength overwrap for heavy articles
- Advantages: high strength, good clarity, thermal stability, ink wettability, and adhesion
- Disadvantages: high price

Polyethylene: Linear Low Density Polyethylene (LLDPE)[1171]

- Used where high strength is required;often coextruded with LDPE for lower costs
- Advantages: low shrink temperature, broad heat-seal range, good low-temperature properties
- Disadvantages: poor machinability, high tear propagation

Polyethylene: High Density Polyethylene (HDPE)[1171]

- Used where high barrier and strength are required
- Advantages: low water vapor transmission rate (WVTR), moderate stiffness, low price
- Disadvantages: poor appearance, cutability, printability, and machinability

Polypropylene[1171]

- Often used where the preservation of the product appearance is key
- Advantages: excellent optics
- Disadvantages: high tear propagation

Polypropylene: Oriented Polypropylene (OPP)[1171]

- Often coated with PVDC to improve oxygen barrier
- Advantages: excellent optical and moisture barrier properties, grease-resistance, good strength and durability, good thermal properties

Table 1. Packaging Applications, Material Requirements, and Materials Used[1171]

Application	Material Requirements	Materials Used
Meat and poultry	low temperature durability; high temperature durability (microwave)	coextruded or laminated EVA ionomers, PVDC, nylon, polyester
Snack food	good machinability; print-stiffness; barrier properties	cellophane, OPP, polyester, HDPE
Cheese	barrier properties; strength	laminations or coextrusion with PVDC on a base film of cellophane, polyester, nylon or PP
Bakery products	machinability; low costs	coated or coextruded OPP, cellophane
Medical	sterilization properties; strength	90% PVC and LDPE, 10% specialty films

- Disadvantages: moderate price

Polyvinylidene chloride (PVDC):[1171]

- Often used where oxygen and flavor barriers and/or excellent optics are required
- Advantages: low permeability, excellent optics, strength
- Disadvantages: high cost

Polyvinyl chloride (PVC):[1171]

- Often used in shrink-film applications
- Advantages: clarity, sealability, low shrink tension
- Disadvantages: film relaxation, high cost

As the technology of packaging improves, so do the available options, coatings, and multilayer packaging offer a designer almost unlimited packaging potential. The materials of packaging continue to become better and stronger. *Stay tuned.* The next packaging milestone is just around the corner.

2.0 Test Methods

The primary test methods observed in the US are published and maintained by ASTM International[2031] (formerly known as The American Society for Testing and Materials), the International Organization for Standardization (ISO), and the German Standards Institute (Duetsches Institut fuer Normen or DIN). These test methods are also used internationally.

The following ASTM testing descriptions are some of the most common test methods used for the films discussed in this publication. For full test details, please review the appropriate testing references.

2.1 Tests for Physical Properties

Tensile Properties of Thin Plastic Sheeting. Primary Film Test Method: ASTM D882; Additional Tests Methods: ASTM D638, D1708, and ISO 527. The primary test method, ASTM D882, is used for the determination of tensile properties of plastics in the form of thin sheeting (less than 1.0 mm in thickness).This includes film which has been arbitrarily defined as sheeting having nominal thickness not greater than 0.25 mm.

Tensile strength refers to the maximum stress the film can sustain before it actually fractures; quite literally, the amount of force necessary to pull a material apart. The SI unit of tensile strength is the pascal (English units are pounds per inch of original cross-sectional area). Elongation refers to the amount the material will stretch before breaking.

Tensile modulus is a measure of the force required to deform the film by a specific amount. It is a measure of the film's stiffness.

The following material properties can be calculated from the tensile strength test (at yield and at break): tensile strength, tensile modulus, strain, elongation and percent elongation at yield, and elongation and percent elongation at break. (See Fig. 1.)

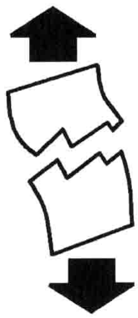

Figure 1. Tensile and elongation, ASTM D882.[1080]

For a specimen sample, ASTM D882 uses strips cut from thin sheet or film; ASTM D638 requires a Type I standard dumbbell-shaped tensile bar.

Impact Resistance of Plastic Film by the Free-Falling Dart Method. Primary Film Test Method: ASTM D1709; Additional Test Method: ISO 7765-1. A weighted dart is dropped from a standard height onto a taut sample. Depending upon the expected impact strength of the test sample, either method A or method B is chosen. The method defines the dart size and the drop height for the dart. Test method A specifies a dart with a 38 mm diameter dropped from 0.66 m. Test method B specifies a dart with a 51 mm diameter dropped from 1.5 m.

The dart unit is the weight of dart in grams that breaks the sample fifty percent of the time, also called failure weight. These tests give an index of the material's dynamic strength and predict resistance of a material to breakage from dropping or other quick blows.

Pendulum Impact Resistance of Plastic Film. Primary Film Test Method: ASTM D3420. Sometimes called Spencer Impact, ASTM D3420 covers the determination of resistance of film to impact-puncture penetration at ambient temperatures.

Initial Tear Resistance of Plastic Film and Sheeting. Primary Film Test Method: ASTM D1004. At very low rates of loading, 51 mm/min, ASTM D1004 covers the determination of the tear resistance of flexible plastic film and sheeting. Tear resistance measures the ultimate force required to initiate tearing in a film or sheet, as measured in newtons.

The specimen is die cut from a sheet or film. The shape of the specimen produces a stress concentration in a small area of the specimen. The maximum stress, usually found near the outset of tearing, is recorded as the tear resistance.

Propagation Tear Resistance of Plastic Film and Thin Sheeting by Pendulum Method, Elmendorf Tear. Primary Film Test Method: ASTM D1922. Tear strength is the force necessary to continue tearing a sample after a nick has been made; it is reported in grams.

A pendulum is released from a raised position, and a scale registers the arc through which the released pendulum swings. Samples of film are clamped into the tester and nicked to start the tear; then the pendulum is released. This tears the sample and the scale registers the arc. As the arc is proportional to the tear strength of the sample, calibration of the arc gives the tear strength.[1080]

Elmendorf Tear testing can be performed on three types of standard samples; however, the constant radius sample is the preferred test sample for plastic films. (See Fig. 2.) This sample provides a constant radius from the start of the tear strength measurement—useful for materials where the tear may not propagate directly up the sample as intended.[1169]

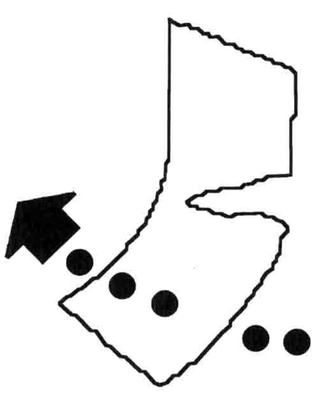

Figure 2. Tear strength, ASTM D1922.[1080]

Sample thickness is also reported, although there is no direct relationship between thickness and the tearing force. Thus, only results for samples of the same thickness can be compared.[1169]

This test is very important for all films as well as for paper. High tear values may be needed for machine operations or for package strength. However, low tear values are necessary and useful for easy opening of some package types.[1080]

Coefficient of Friction. Primary Film Test Method: ASTM D1894. The coefficient of friction (CoF) test is used to measure the static (starting) and kinetic (sliding) resistance of the film when sliding over another surface, either film-to-film or film-to-metal. Coefficient of friction is the ratio of the frictional force to the force, usually gravitational, acting perpendicular to the two surfaces in contact. The static CoF is representative of the force required to begin movement of the surfaces relative to each other. (See Fig. 3.) The kinetic CoF is representative of the force required to sustain this movement.[1080]

Figure 3. Coefficient of friction (CoF), ASTM D1894.[1080]

The film sample specimen, 64 mm square, is attached to a "sled." The second surface, 254 mm × 127 mm, remains fixed as the sled is pulled across at a controlled rate. The frictional force is measured by a stream gauge.[1080][1169]

Folding Endurance of Paper by the M.I.T. Tester. Primary Film Test Method: ASTM D2176. The folding endurance test is used for determining the folding endurance of paper and plastic by use of the M.I.T. tester. It is recommended for papers/films less than 0.25 mm. This test method is the technical equivalent of TAPPI T511.

Bursting Strength of Paper. Primary Film Test Method: ASTM D774; Additional Test Methods: ISO 2758 and TAPPI 403. The test method ASTM D774 covers measurements of the bursting strength of paper and paper products occurring as single or laminated flat sheets not over 0.6 mm in thickness having a bursting strength of 30 kPa up to 1400 kPa (4 psi up to 200 psi).

2.2 Tests for Permeability Properties

Water-Vapor Transmission. Primary Film Test Method: ASTM E96. The primary test method for the determination of water-vapor transmission through plastics less than 32 mm thick is ASTM E96. (See Fig. 4.) There are two basic methods; the Desiccant Method and the Water Method. Agreement between the two methods should not be expected. The method selected should be the one which most nearly approaches the conditions of use.

- *Desiccant Method:* A desiccant covered by the film to be tested and placed in a humid chamber. Moisture from the chamber permeates the film and is picked up by the desiccant. After a measured period of time the test dish is reweighed and the water vapor transmission rate (WVTR) of the material is calculated.
- *Water Method:* A cup is filled with distilled water and covered with the plastic film. Vapor loss through the test sample is determined through periodic weight-loss measurements.

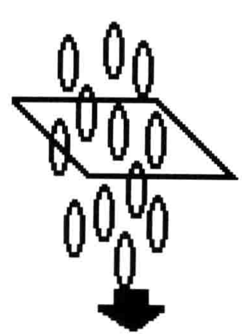

Figure 4. Water-vapor transmission rate (WVTR), ASTM E96.[1080]

The WVTR is reported as grams of water which will pass through a given area of the material in a specified time.

The WVTR is significant for packaging a product which must be prevented either from drying out or from picking up moisture from the surrounding atmosphere.[1080]

Water Vapor Transmission Rate (WVTR) Through Plastic Film and Sheeting Using a Modulated Infrared Sensor. Primary Film Test Method: ASTM F1249. A procedure for determining the WVTR through flexible barrier materials, film, and sheet up to 3 mm in thickness is known as ASTM F1249.

The WVTR, the permeance of the film to water vapor, and the water vapor permeability coefficient may be determined from this test.

Gas Permeability Characteristics of Plastic Film and Sheeting. Primary Film Test Method: ASTM E96. The following material properties may be determined through ASTM D1434:

- Gas transmission rate (GTR)
- Permeance
- Permeability

Specially constructed cells are used to measure the gas transmission rate. After a film sample has been clamped into a cell, test gas is flushed through chambers on both sides of the sample. Test gas is admitted to one side of the sample; the test chamber on the other side is evacuated, and gas is allowed to permeate through the film sample into the evacuated chamber for a measured length of time. Using the geometry of the cell and film sample, with the measured pressure and temperature of the test gas which permeated the sample, the GTR can be calculated. (See Fig. 5.)[1080]

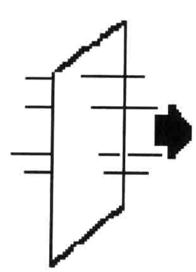

Figure 5. Gas transmission rate (GTR), ASTM D1434.[1080]

Gas permeability is usually reported in cubic centimeters of gas that pass through a square meter of film in 24 hours when the gas pressure differential on one side of the film, at a specific temperature, is one atmosphere greater than that on the other side.[1080]

Gas transmission rate is vital in vacuum and gas packaging and for packaging fresh produce items that must breathe.[1080]

2.3 Tests for Optical Properties

Specular Gloss of Plastic Films and Solid Plastics. Primary Film Test Method: ASTM D2457. Specular Gloss is a measure of the light reflected by the surface of a plastic film. ASTM D2457 provides three separate gloss angles:

- For intermediate-gloss films: 60° is recommended
- For high-gloss films: 20° is recommended
- For intermediate and low-gloss films: 45° is recommended

Gloss is measured on a glossmeter, an instrument having an incandescent light source and a photosensitive receptor that responds to visible light. Light is shown onto the sample at a specified angle. The fraction of the original light that is reflected onto the photosensitive receptor is called gloss. (See Fig. 6.)

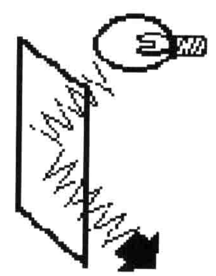

Figure 6. Gloss, ASTM D2457.[1080]

Gloss can be inherent in the material, a result of the molding process, or a result of surface texture. Gloss can also be affected by environmental factors such as weathering or surface abrasion. Thus, gloss can be useful in product and process development and end-use performance testing.[1169]

Gloss is an important merchandising factor and this test makes it possible to specify and control this surface characteristic so that the desired effect will be ensured.[1080]

Haze and Luminous Transmittance of Transparent Plastics. Primary Film Test Method: ASTM D1003. Haze is the scattering of light as it passes through a transparent material, resulting in poor visibility and/or glare. Luminous transmittance measures the amount of light that passes through a sample. (See Fig. 7.)[1169]

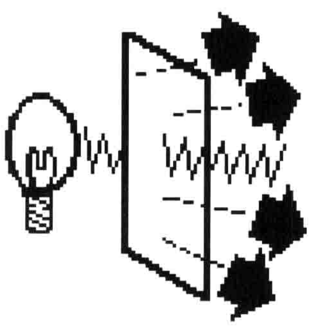

Figure 7. Haze and luminous transmittance, ASTM D1003.[1080]

The evaluation of specific light-transmitting and wide-angle, light-scattering properties of planar sections of materials, such as essentially transparent plastic, is covered by ASTM D1003.

The haze of transparent packaging materials is measured on a special haze meter where the sample is placed between an incandescent light source and geometrically arranged photocells. The amount of light transmitted by the sample, the light scattered by the sample and the instrument, and the total incident light are measured. From these values the percentage of transmitted light that is scattered can be calculated. The haze meter measures these variables and interrelates them so that the percentage of scattered light can be read on the meter.[1080]

This test is important to products or in uses where true color and visibility are required.[1080]

Haze can be inherent in the material, a result of the molding process, or a result of surface texture. Haze can also be a result of environmental factors such as weathering or surface abrasion.[1169]

Index of Refraction of Transparent Organic Plastics. Primary Film Test Method: ASTM D542; Additional Test Method: ISO 489. The index of refraction is the ratio of the velocity of light in a vacuum to the velocity of light in a transparent material.

A sample about 6.3 × 12.7 mm with a flat polished surface is placed on the prism of a refractometer. Generally, the refractometer will provide a digital representation of the refractive index.

2.4 Tests for Electrical Properties

Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies. Primary Film Test Method: ASTM D149; Additional Test Method: IEC 80243. Dielectric strength measures the material's ability to act as an insulator; the higher the dielectric strength, the better the insulation properties. Dielectric strength is expressed as volts per unit thickness and represents the maximum voltage required to produce a dielectric breakdown through the material.[1169]

Any specimen thickness can be used; the most common thickness is between 0.8 and 3.2 mm.[1169]

The test specimen is placed between two electrodes in air or oil. To test for the breakdown voltage, voltage is applied across two electrodes and increased from zero until electrical burn-through punctures the sample, or decomposition occurs.[1169]

AC Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulation. Primary Film Test Method: ASTM D150; Additional Test Method: IEC 60250. The ability of an insulator to store electrical energy can be measured through the dielectric constant, which is the ratio of the capacitance induced by two metallic plates with a film sample between them to the capacitance of the same plates with air or a vacuum between them. Better insulating materials have lower dielectric constants. Higher dielectric constants are used when high capacitance is needed.[1169]

The dissipation factor measures the inefficiency of an insulating material and is defined as the reciprocal of the ratio between the insulating material's capacitive reactance to its resistance at a specified frequency.[1169]

The test method ASTM D150 is performed on a flat sample larger than 50 mm in diameter. The sample is placed between two metallic plates and capacitance is measured. A second test is made without the specimen between the two electrodes. The ratio of these two values is the dielectric constant.[1169]

DC Resistance or Conductance of Insulating Materials. Primary Film Test Method: ASTM D257; Additional Test Method: IEC 60093. The test method ASTM D257 covers direct-current (DC) procedures for the determination of insulation resistance, volume resistance, volume resistivity, surface resistance, and surface resistivity of electrical insulating materials, or the corresponding conductances and conductivities.

Surface resistivity (ohms per square) is the resistance to leakage current along the surface of an insulating material. Volume resistivity (ohms-cm) is the resistance to leakage current through the body of an insulating material. The higher the surface/volume resistivity, the lower the leakage current. Also, the material is less conductive.[1169]

A sample is placed between two electrodes and voltage is applied for sixty seconds. The resistance is measured and resistivity is calculated.[1169]

3.0 Units

The data presented in this publication have been normalized, where possible, to SI units. The units are as varied as testing; in fact, some tests provide for the use of SI and English units. Where a source document presented units other than SI, the units were converted and are presented with SI units. Extensive references are included for the user who is interested in more information about the specific materials.

With respect to this data compilation, the base units for the SI system include: meter (m), kilogram (kg), second (s), ampere (amp), and Celsius (°C). Derived units include: newton (N) ($kg \cdot m/s^2$), pascal (Pa) (N/m^2), and joule (J) ($N \cdot m$). Many sources are available to convert from English to SI units.

4.0 Regulations

Materials that come into contact with food and drugs must meet specific requirements. In the US, the regulating body is the FDA. It maintains the Code of Federal Regulations Title 21 (21 CFR), which governs use for food and drugs.

Many manufacturers provide a 21 CFR statement for their materials. The 21 CFR contains many parts, and the numbers that follow 21 CFR xxx detail which part of the regulation applies; for example 21 CFR 177.1520 refers to PE, PP, and polyolefin copolymers.

Packaging films are primarily evaluated for food contact. Within the 21 CFR, the factors that affect food contact status include the following:[1170]

- Chemical composition
- Function (base polymer, additive, colorant, etc.)
- Conditions of use (food type, time and temperature of contact)
- Compliance requirements (concentration limitation, physical properties, extraction tests, etc.)

Additional routes exist for materials to be used in food contact applications, materials sanctioned by the FDA before 1958 and Generally Recognized As Safe (GRAS) for the intended use by qualified experts.[1170]

Broad approvals for drug packaging do not currently exist. Drug packaging is generally evaluated as part of the drug, and some packaging materials are listed in USP and/or European Pharmacopoeia: USP has general requirements for containers and some specific tests for containers made from certain materials; European Pharmacopoeia has some specifications for materials. In both cases, in relation to materials, the listings are intended to characterize similar materials. In neither case do the listings indicate suitability for specific drug products.[1170]