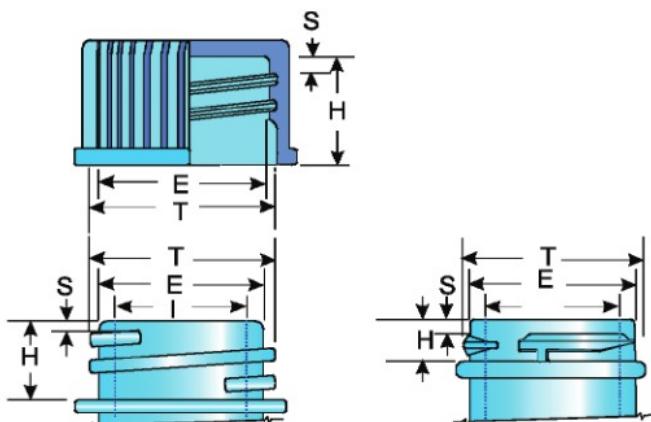


a time over a long period. Reclosability should not be offered with a product that quickly becomes unfit for human consumption once the initial seal is breached. However, reclosability is essential for perishable products like milk, especially for larger bottles and cartons, even though the product will spoil if it's not stored properly or it reaches the end of its shelf life. In those situations, the consumer must decide when the product becomes unfit for use and should be discarded.

- The closure protects product shelf life and may require active and passive barrier properties for sensitive products.
- The closure must be “user-friendly,” with easy opening and, where applicable, easy and secure resealability. It is increasingly unacceptable to have a closure that requires a tool for opening.
- Economics are an ever-present aspect of any packaging design choice. Economics includes not just closure cost, but also the cost of application and production losses.
- Closure convenience features such as applicators, measurement devices and dispensers are sure to catch the eye of the convenience-minded consumer.
- In addition to protecting the product, the closure is sometimes required to protect the consumer. Tamper-evident (TE) closures and child-resistant (CR) closures are obvious examples. Closures must not have sharp edges or corners and should not create debris that might be hazardous.
- Is the product aimed at a specific market segment? Products for seniors, for example, must accommodate weaker, possibly arthritic fingers. Closures designed for hospital use are designed to maximum sterility confidence.
- Is the product hazardous? Special closures have been designed that allow the safe measurement and dispensing of dangerous chemicals. Venting closures are used where internal pressure buildup is a factor.
- Is there a particular persona that will provide a marketing advantage? Stock containers are used in many packaging applications, and the only way to create a unique appearance may lie in the label graphics or the choice of the closure system.
- Closures and dispensers should be recyclable or, at least, not detrimental to recycling streams. Many municipal recycling systems accept closures and dispensers, but poor closure design can negatively impact materials being recycled. The *APR Design® Guide* (<https://plasticsrecycling.org/closures-dispensers>), developed by the Association of Plastic Recyclers, helps package designers evaluate a closure design against industry-accepted criteria and ensure it is recycling-compatible. Sustainability and recycling are discussed extensively in Chapter 5, Environmental and Sustainability Issues.

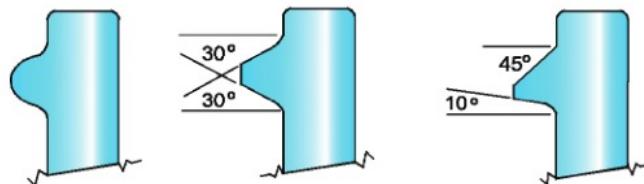
## **CONTAINER AND CLOSURE DIMENSIONING**

Industry-wide standards for finish specifications have been established. Finish dimensions are identified by letters of the alphabet and correspond to related dimensions on the closure. (See Figure 13.1, Table 13.1)



**Figure 13.1**  
Standard finish dimension nomenclature for a continuous-thread closure (left) and a lug-type closure (right). Closure dimension nomenclature mirrors container finish nomenclature.

- E Thread root diameter.
- I Diameter at smallest opening inside finish.
- H Top of finish to top of bead or to intersection with bottle shoulder on beadless designs.
- T Thread diameter measured across the threads.
- S The vertical distance from the top of the finish to the start of the thread.



**Figure 13.2**  
A rounded thread profile typical of older glass finishes (left). L-style (center) and M-style (right) thread contours are used primarily with plastic containers.

Originally, the Glass Packaging Institute kept closure and finish standards. As plastic closures came on stream, it became evident that the rounded contour of glass threads was not suitable for plastic closures. The Society of the Plastics Industry, now the Plastics Industry Association, developed two profiles to be used with plastic bottles. M-style thread-engaging surfaces are angled at 10 degrees, and L-style threads are angled at 30 degrees. (See Figure 13.2) ASTM D2911, Standard Dimensions and Tolerances for Plastic Bottles, provides detailed dimensional descriptions of L- and M-style thread profiles for plastic bottles. The responsibility for maintaining both glass and plastic closure standards and tolerances was assumed by The Closure and Containers Manufacturers Association and now resides with the International Society of Beverage Technologists (ISBT). ISBT also has undertaken the responsibility of standardizing plastic beverage container finishes. Guidelines for an extensive array of closure styles and diameters may be found at ISBT's [www.threadspscs.com](http://www.threadspscs.com).

**Table 13.1**  
**Nomenclature for finish dimensions.**

A = Tamper-evident bead diameter	M = Construction gauge pt on support ledge
B = Tamper-evident band recess diameter	P = Thread pitch (measured from K)
B1 = Tamper-evident band secondary recess diameter	P = Parting line
B = Helix at pitch diameter	PLK = Height from TOF to the gauge pt of first full thread taken at parting line (clockwise from thread start position)
C = Control diameter at TOF	S = Height from TOF to start of full depth of thread
D = Tamper-evident bead height measured from TOF to gauge pt	T = Thread crest diameter
E = Thread root diameter	TEA = Tamper-evident band angle
F = Upper ring diameter	TOF = Top of finish
G = Lower ring diameter	V = Control diameter depth
H = Clearance height required for proper closure function	W = Width of bead
I = Minimum diameter through finish	X = Height from TOF to bottom of support ledge
J = Height from TOF to top of tamper-evident bead	Y = Seal control length
K = Height from TOF to the gauge pt at start of full thread (at thread start position)	Z = Maximum diameter on support ledge
L = Height from TOF to top of bead	

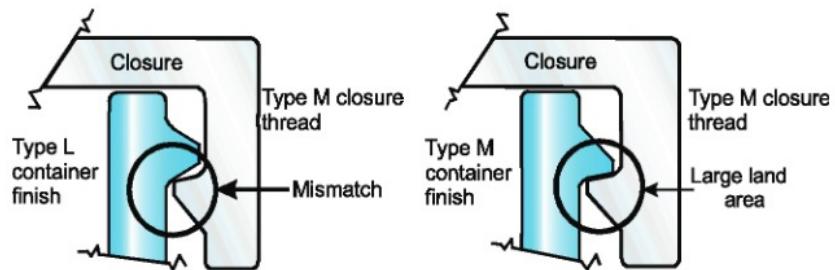
*Source: ISBT.*

Outside of North America, standards from the International Technical Centre for Bottling (Cetie) at [www.cetie.org/en/presentation-of-the-ceties-documentary-database\\_122.html](http://www.cetie.org/en/presentation-of-the-ceties-documentary-database_122.html) are commonly referenced and provide specifications and guidance documents for a wide range of commonly used finishes and closure types.

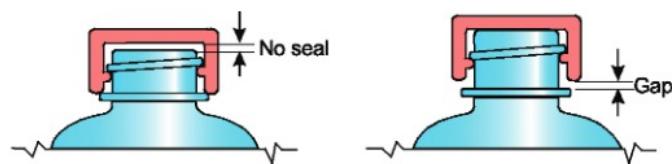
Depending on the type and end-use of a closure, there could be additional requirements and specifications. Two additional reference documents include:

- The International Safe Transit Association has many e-commerce standards ([www.ista.org/test\\_procedures.php#member-performance-section](http://www.ista.org/test_procedures.php#member-performance-section)).
- The United Nations has standards for the safe shipment of materials and offers guidance documents (<https://digitallibrary.un.org/record/94473?ln=en>).

The L-style thread is considered by some capmakers to be more modern and easier to manufacture and line, but the M-style, or modified buttress thread, provides a more secure fit and allows for more margin of error on older bottle molds.



**Figure 13.3**  
Mismatched threads on the finish and closure will not engage properly.



**Figure 13.4**  
Conditions where closure S or H dimensions are mismatched.

Some cap companies have ceased manufacturing the M-style because it is more difficult to make. More recently, lightweighted designs feature shorter height finishes, lighter finishes and/or thinner wall thicknesses. These changes reduce resin usage, support sustainability goals and offer potential cost benefits.

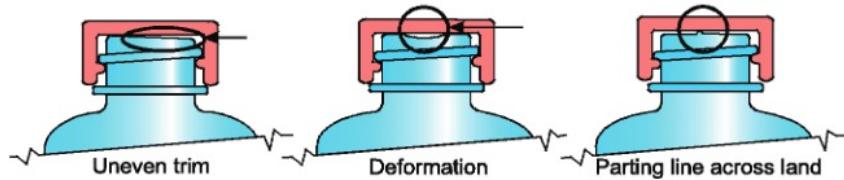
Closure and bottle finish dimensions must match closely to effect a proper seal. A mismatch invariably results in leaking bottles or other closure problems. (See Figure 13.3) If the bottle's T or E dimensions are too large, or if the closure T or E dimensions are too small, there will be resistance to turning the closure. This can lead to torque problems. In the opposite situation, where the bottle's T or E dimensions are too small, or the closure's T or E dimensions are too large, the threads will not engage the full thread land area. This will cause torque retention problems. Stripping torque will be low, or in extreme cases, the threads will not engage. A plastic bottle's finish is often slightly oval. This can lead to a combination of problems having the characteristics of both of the above situations.

If the bottle's H dimension is small, the cap will bottom out on the bottle neck bead or shoulder before a tight seal can be achieved at the closure land. (See Figure 13.4, left) If the bottle's H dimension is too large, the closure skirt may be too high above the bottle bead or shoulder. (See Figure 13.4, right) This could be a serious problem in instances where the skirt is intended to enclose the bead, as in TE closures. If a bottle's S dimension is too short, the closure could wind down past the bottle thread, resulting in partially unengaged threads. Similarly, if the bottle's S dimension is too long, some closure threads may not completely engage the finish threads.

Bottle finish defects also can cause leakage. Pitted, rough, deformed or scored land surfaces, uneven trim or cupped trims are difficult to overcome even with properly specified and precisely manufactured closures. (See Figure 13.5) Extrusion-blow-molded bottles may have a mold parting line going directly across the sealing area. An overly prominent parting line could interfere with the proper seating of the closure liner system. Injection-blow-molded containers have the advantage of not having a parting line in this critical area.

**Figure 13.5**

Uneven trim or other finish land area deformation can result in product leakage.

**Table 13.2**

**Selected common closure code groups. The abbreviation "CT" indicates a continuous-thread closure.**

Designations	Description
120, 140 and 160	two-, four- and six-lug Amereseal quarter-turn finish
400	series shallow CT finish
401 - with wide sealing surface	
410 - medium CT concealed-bead finish	
415 - tall CT concealed bead-finish	
425 - 8-15 mm shallow CT	
430 - pour-out CT	
445 - deep S CT	
460 - home canning jar finish	
600	beverage crown finish
1240	vacuum lug-style finish
1600	roll-on finish
1620	roll-on tamper-evident finish
1751	twist-off vacuum seal
SP 100	T for plastic SP 100 finish
SP 103	CT for plastic SP 103 finish
SP 200	CT for plastic SP 200 finish
SP 444	CT for plastic SP 444 finish

Closures are designated by their inside diameter in millimeters followed by a number that designates style. (See Table 13.2) For example, a 22-400 closure identifies a closure that has an inside diameter of 22 millimeters (mm) and will fit a 400 finish. A 400 finish is identified by ISBT as a shallow continuous-thread (CT) finish. Designations 120, 140 and 160 identify two-, four-, and six-lug closures. The 1600 series describes roll-on-type closures. The designation numbers have been arbitrarily assigned; there is no dimensional significance to the digits.

## METAL CLOSURES

### Threaded Metal Closures

Threaded closures engage a thread on the container finish, and rotation draws the closure against the container finish. The amount of rotation required to effect a seal varies depending on the container and closure, but 360 degrees or more is typical.

Threaded metal closures are classified as either CT (continuous thread, distinguished by sizes of 40 mm or more) or as CTB (for sizes of 38 mm or less). The types are similar, but the larger CT styles will have a strength or stacking reinforcement designed into the top or crown panel, often in the form of an embossed ring.

Threaded closures generally are made from steel, with some smaller types being formed from aluminum. Sheet metal receives various protective and decorative coatings and lacquers on the closure's interior and exterior faces before being formed. This allows the closure's top panel and side to be fully decorated. The prepared metal is cut into strips and then proceeds through a multistage forming process. Newer presses accept full sheets, eliminating the need to cut strips.

The forming process involves cutting a blank and forming a shell of the overall shape and dimension of the finished cap. The threads are formed, the top panel is configured, and the wire edge or sharp shell edge is rolled over. The final step forms the knurled "finger grip" around the closure sides. The fully formed closure is now ready to be lined with an inserted piece or flowed-in plastisol.

### Lug-Style Metal Closures

Production methods for twist or lug closures are similar to those for threaded closures. (See Figure 13.1) Lug closures are under more stress than screw closures and therefore are normally a heavier gauge of metal. Sizes range from 30–110 mm with smooth or fluted sidewalls.

Lug closures are designed to engage the interrupted thread of the container finish. The interlocking of the cap's lug and the container's thread creates a camming action, drawing the closure down until the soft liner forms a hermetic seal. The lug closure's advantage is that the seal is accomplished with fewer degrees of rotation (typically less than 90 degrees) than a standard screw thread. This enables faster and more positive application.

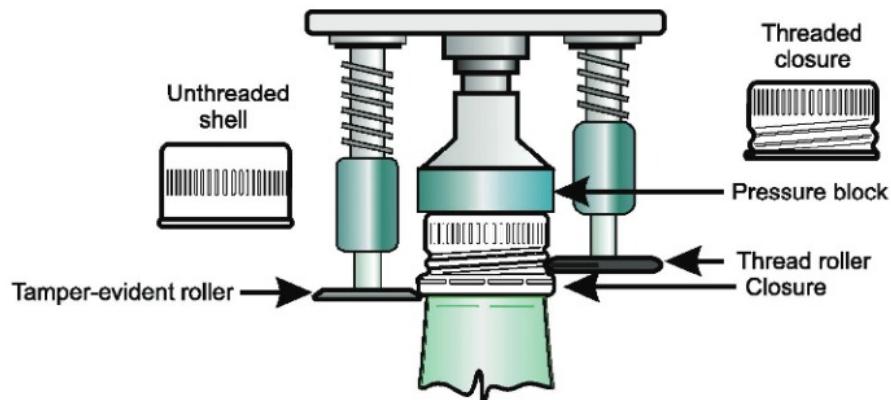
Glass jar lug threads are easier to make than continuous threads. Lug cap closures are being used on plastic containers.

### Roll-On Metal Caps

The roll-on metal cap is punched from coated and decorated aluminum sheet and formed into a cap shell with a liner added to suit the end-use. There are no threads at this point. The packager drops the preformed shell over the container finish, and the capping machine rolls the cap's sidewalls into the bottle's finish, duplicating the threads. (See Figure 13.6) A top pressure block ensures that the liner material contours properly to the top surface of the finish.

**Figure 13.6**

Roll-on closure threads are formed by forcing the aluminum shell to conform to bottle finish threads.



Roll-on closures can be made TE by folding an extension of the closure skirt around the bottle's neck ring or bead. Circumferential perforations around the skirt either break away to leave a portion of the skirt caught beneath the neck ring or flare out to indicate the closure has been opened. Roll-on pilfer-proof caps (commonly referred to as ROPP) come in diameters from 18–38 mm.

## Press-On/Twist-Off Metal Closures

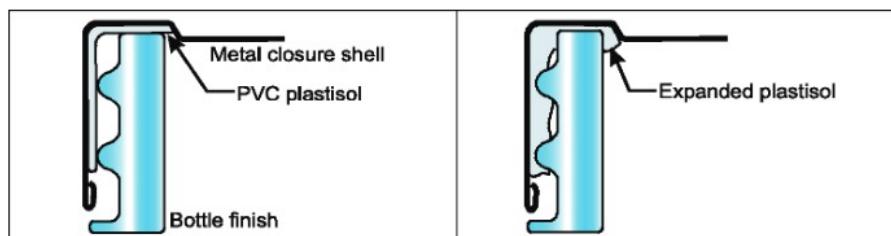
The press-on/twist-off, or PT, metal cap has a flowed-in plastisol gasket. (See Figure 13.7) This gasket softens and conforms to a glass container's finish threads when heated during steam-vapor vacuum sealing. At this point, the closure becomes, in effect, a threaded closure. The end-user simply twists the cap off. It is ideally suited for high-speed vacuum packaging lines since the metal shell is simply pressed onto the bottle finish. Originally designed for baby food, this closure is now the world standard for these and other products in diameters from 38–70 mm.

A TE feature can be added if the closure top is embossed with a ring in the center of the closure to provide an “oil canning” or flexing movement. The internal vacuum draws the ring section down. When the seal is broken, the depressed ring portion pops upward with an audible sound.

Other vacuum closure variations hold a flat metal panel against the bottle finish by external air pressure; there are no threads. A plastic tear-away ring bonded to the metal panel wraps over a bead on the container finish to provide a “snap-on” lid and tamper evidence.

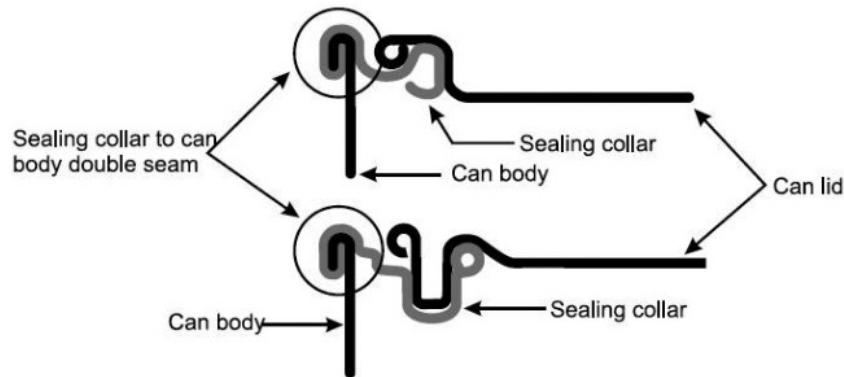
**Figure 13.7**

A press-on/twist-off closure utilizes a plastisol, which expands during steam vapor vacuum sealing to, in effect, become a threaded closure.



**Figure 13.8**

A simple friction-fit metal can lid (top) and a double tight metal can lid such as would be used on a paint can. Friction-fit metal can ends also are known as lever lids.



## Crown Closures

Crown closures are the familiar crimped-on metal caps for beers, carbonated drinks and ciders. Regardless of the product, all crowns are 26 mm in diameter and made to one North American standard. The crowns are cut and formed from pre-decorated steel. Linings are either preformed and bonded into position or formed from a flowed-in plastisol or other polymeric material. An oxygen scavenger sometimes is incorporated into the liner material for oxygen-sensitive products such as beer.

The twist-off crown is a variation. These crowns are made of slightly lighter gauge, reduced-temper steel than regular crowns. This allows the material to form into the bottle thread. Removal is aided by the inclusion of liner and interior lacquer lubricants.

Both pry-off and twist-off crowns are applied by a hollow metal mandrel that comes down over the crown and bends the crown skirt down to conform with the bottle finish. If the finish has a thread configuration, the crown skirt takes on this shape.

## Friction-Fit Pry-Off Metal Closures

Friction-fit metal can ends require a sealing collar or lever ring to be double-seamed to the can body. The ring is cut from a flat sheet and formed to the proper geometry to avoid having a seam along the ring's circumference.

For dry products, a single point of friction as shown in Figure 13.8 (top) is adequate. Paint cans must seal in solvent vapors and prevent product oxidation or drying. An extra fold in the closure provides an additional sealing surface. The sealing collar and can lid geometries offer two points at which a seal is made; hence the term double tight or doubletite. (See Figure 13.8, bottom)

## CLOSURE SEALS

### Lined Closures

To make a hermetic seal, a closure must have a means of drawing the inner face of the closure snugly against the container and sealing it tightly against the bottle finish. The latter requirement can be achieved through the use of resilient liners inside the closure that conform to the minute irregularities of the finish surface to effect a seal.

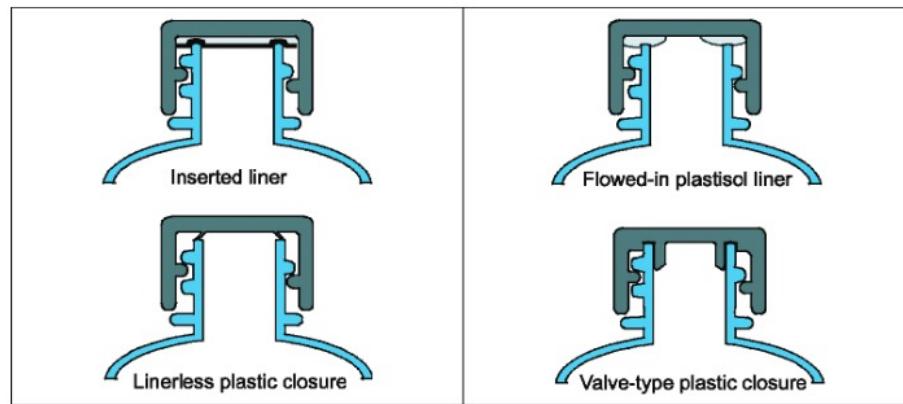
Early liners were thin cork sheets or pulpboard. Currently, most liners are composed of soft, resilient material, such as expanded plastic, which conforms to the container's finish. Often, the resilient backing is combined with other materials to create the actual barrier and seal. (See Table 13.3) Expanded polyethylene (EPE) in various densities is the most common resilient material for general-purpose closures. Lower densities would be used where a high degree of conformity or compressibility is required. However, lower densities tend to have poorer torque retention. Where hot fills or induction heat seals are used, expanded polypropylene (EPP) is a better choice. Sometimes solid ethylene-vinyl acetate (EVA) or solid synthetic rubber inserts can serve both conformability and sealing functions.

Liners of plastisol, a polyvinyl chloride, are flowed in and then oven-cured to a solid or expanded to a soft, rubbery state.

High-barrier liners are made with laminations that include aluminum foils faced with a high-strength material such as polyethylene terephthalate (PET). Where metal cannot be used, a laminate incorporating ethylene vinyl alcohol (EVOH) will provide a good gas barrier. Thermoplastic elastomers combine heat tolerance and oxygen barrier making them a good candidate for liners for hot-fill, cold-fill and aseptic applications. EVA, nylon and polyvinylidene chloride are common facing layers for barrier liners. For sensitive products, liners may incorporate an active barrier like a desiccant or oxygen scavenger.

**Table 13.3**  
**Examples of common closure liner constructions and applications. (Source: Tri-Seal International Inc., Dustin Vance.)**

Construction	Characteristics and Applications
PE/expanded PE/PE	General-purpose applications
PP/expanded PP/PP	Hot-fill applications
PP/expanded EVA/PP	Hot-fill applications
Three-layer PP coextrusion	Hot-fill applications
Thermoplastic elastomers	Hot-fill, cold-fill, aseptic applications
Ethylene-vinyl acetate	Warm fills, beverages, motor oil
EVA/expanded EVA/EVA	Resilient, highly compressible
PE/isobutylene blend	Inert, fair gas and moisture barrier
PET/LDPE/expanded LDPE/LDPE	Good gas barrier
EVA/EVOH/LDPE/expanded LDPE/LDPE	Good gas barrier
EVA/PA/LDPE/expanded LDPE/LDPE	Good gas barrier
PVDC/LDPE/expanded LDPE/LDPE	Good gas barrier
PET/LDPE/foil/expanded LDPE/LDPE	Superior gas barrier

**Figure 13.9**

Four approaches to creating a seal: Inserted friction-fit liner (top left), flowed-in plastisol liner (top right) and two plastic linerless closures (bottom).

Liners must be physically and chemically compatible with the active ingredients they will contact. An adequate barrier to gas and moisture transmission into or out of the container may be needed for some products.

Some products require that it be possible to vent any internal pressure buildup. This is usually accomplished by special treatments of the closure liner material.

In addition to the sealing mechanism mentioned above, other barrier systems can be used in closures to further protect the product from sources such as oxygen or light permeation. The active or passive systems typically are employed during the blending/layering or adhering process and also can be used in linerless closures. (See section, Linerless Closures, below) Barrier materials should be chosen carefully to determine their efficacy in the total package—performance in relation to cost and impact to the supply chain and the environment.

Like all packaging, liners are addressing sustainability concerns with the development of structures that reduce plastic content, contain substantial levels of post-industrial recycled plastic and/or will not be a contaminant when the closure is recycled.

## Induction Innerseals

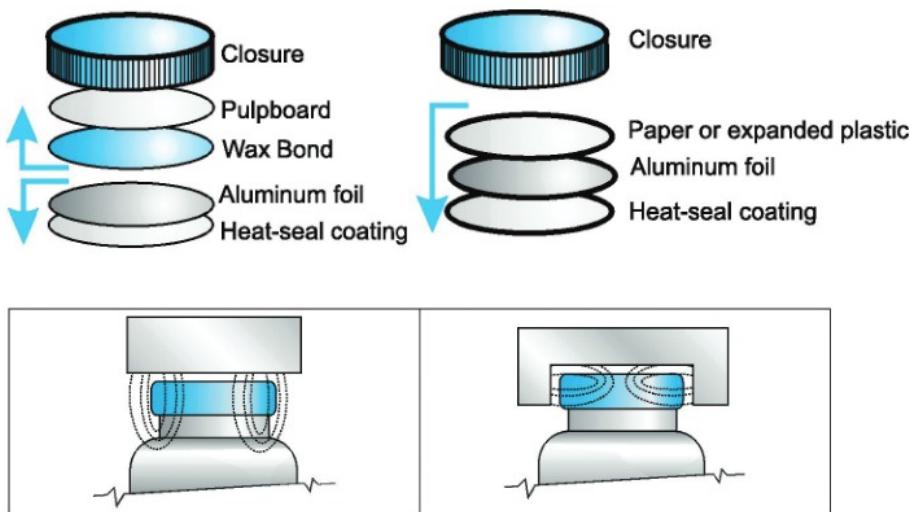
Induction innerseals across the container opening provide a hermetic seal as well as barrier and tamper evidence. Benefits include enhanced shelf life and spill protection. These liners are inserted by the closure manufacturer as part of the cap-lining operation or can be applied separately by using a “capless” sealing process.

Induction heat-sealing heads have sealing coils powered by generators running at 50 to 500 kilohertz; they produce energy that couples with the aluminum foil that is part of the innerseal. The foil’s temperature rises and transfers heat to the heat-seal coating, which then bonds with the container’s land area. Low-frequency generators provide a broad heated band around the seal perimeter, while high-frequency generators concentrate the heat more in the perimeter zone. There is no contact between the sealing coils and the closure. Low-frequency systems tend to be used where a wax bond must be released and also for larger closures.

One common induction seal liner consists of an aluminum foil disk temporarily adhered to a pulpboard liner with wax. (See Figure 13.10, left) Poly-coated structures also are used for innerseals.

**Figure 13.10**

Two types of liner system used for induction heat-sealed innerseals.

**Figure 13.11**

Induction sealing coils can be designed to generate different field shapes. Ferrite "energy directors" are used to direct most of the field to the sealing zone.

In the foil/wax/paperboard configuration, the container side of the aluminum foil disk is coated with a hot-melt adhesive. The entire liner assembly is inserted into the closure like a regular liner. When the cap is applied to the container, the foil liner presses against the finish sealing surface (land). The container passes under an induction sealing head, where the high-intensity alternating magnetic field induces eddy currents in the foil disk. (See Figure 13.11) This results in resistance-type heating effects. The heat melts the wax, which then soaks into the pulp liner, while the molten heat-sealable coating bonds the foil to the container finish.

The molten wax soaking into the backing pulpboard reduces the overall thickness of the liner material and results in an immediate loss of closure torque. In critical situations, a second application or adjustment of closure torque may be necessary.

Many closures, especially dispensing closures, need clear access to the orifice. In such instances, a pulpboard liner is undesirable since it remains inside the closure. For these applications, the foil is permanently bonded to a paper or plastic backing. (See Figure 13.10, right.) This liner is held in place by friction. After induction sealing, it stays attached to the container finish.

Innerseals also can be adhered to the top of the container finish with an adhesive. With glassine liners, adhesive is applied to the container finish before the cap is applied. Another type uses a pressure-sensitive wax-adhesive combination.

A sufficiently wide land area and defect-free bonding surface are necessary for successful induction sealing—regardless of the structure of the innerseal.

## Linerless Closures

Some closure designs eliminate the need for liners. These linerless designs are commonly specified for beverage bottles and feature integral sealing structures. Sealing is accomplished by bearing down on a molded-in projecting ridge or vane

or by incorporating a plug-like form or valve that will be forced into the container opening. (See Figure 13.9) The latter designs are known as plug or bore seal closures.

Linerless closures can reduce material costs, offer lower removal torque and simplify operations by eliminating the need for a lining machine or induction sealer. Linerless designs tend to be less forgiving of surface finish variations and often are finish-specific. For example, the primary sealing feature on the closure has tight tolerances and is designed to exert a particular force onto the bottle finish. If the bottle dimensions are such that the primary sealing feature imparts too much force onto the bottle finish, it may be difficult to apply the closure. This can happen when the primary sealing feature tries to enter the inner bore of the bottle and it is smaller than the dimension specified. If bottle dimensions are larger than specified, the primary sealing feature may not impart enough force on the bottle finish to prevent the package from leaking.

Linerless closures may incorporate up to three sealing features, which interact with either the inside, outside or top surface of the bottle finish. Typically, a closure designed for a package requiring higher performance relies on more than one sealing feature. Examples include containers for products that possess a long shelf life, are hot-filled or need to hold large amounts of pressure. Packages for products with less stringent requirements, e.g., refrigerated products, may only require a single sealing feature.

Linerless closures made of high-density polyethylene can offer barrier properties similar to or better than lined closures. However, oxygen-sensitive products may need to blend an oxygen scavenger additive with the resin before molding.

## PLASTIC CLOSURES

### Thermoset Closures

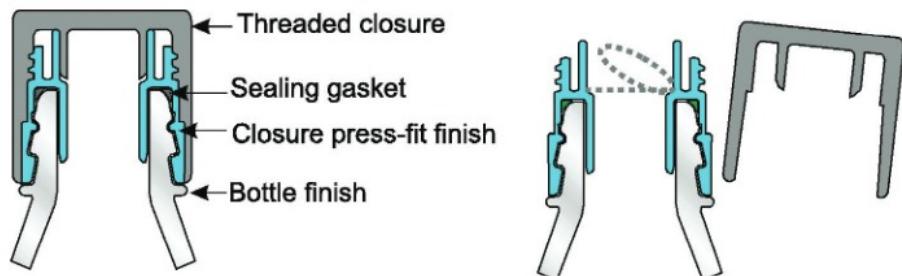
Plastic closure materials can be classified as thermosets or thermoplastics.

Once the traditional choice of the chemical, pharmaceutical and cosmetics industry, thermosets have largely been replaced by thermoplastics. Thermoset closures are compression molded to close dimensional tolerances either from resins such as phenol-formaldehyde (which produces black and dark colors) or from amino resins such as urea (which give brighter colors). As a polymer class, thermosets have higher use temperatures than thermoplastics, offer better solvent resistance and are not subject to "creep" (viscoelastic deformation) problems.

Thermosets can be formed into heavy cross-sections without the "sink" marks common to thermoplastic shapes. Thermoset materials are ideal surfaces for vacuum metallizing. Lastly, thermosets are stiff and have a hard, substantial feel about them. These latter qualities often are used to advantage in the cosmetics industry.

### Thermoplastic Closures

Thermoplastic closures can be injection molded or compression molded from many polymers, including PP and PE. PP forms easily, colors well and is economical. It is less subject to viscoelastic deformation than PE and has a higher use temperature.

**Figure 13.12**

A press-fit closure assembly where the closure engaging threads are on a separate piece that snaps over interference fit rings on the container finish. The dotted line shows where a tamper-evident seal with a pull ring could be located.

PP has the best integral hinge (live hinge) properties of any plastic. This is important for closures that have hinged flip-top components.

PE is used where elongation or some deformation is needed. For example, some threaded-closure designs are pressed (rather than rotated) onto the bottle finish and rely on the closure material's resiliency to allow the closure threads to override the finish threads. In beverage caps, PE dominates because its elastic properties are advantageous for function (plug seal, TE band). This enhances cost-efficiency and sustainability (easier recycling). Plastic corks for wine bottles need to deform under the interference fit. Snap-on tub lids must have some "give" to be stretched over the slightly larger container rim. PE also has better cold resistance than PP.

To address sustainability goals, it's now possible to source PE and PP closures made with bio-based polymers or recycled content.

Cosmetic closures often are made of polystyrene for its hard, glossy surface and exceptional clarity.

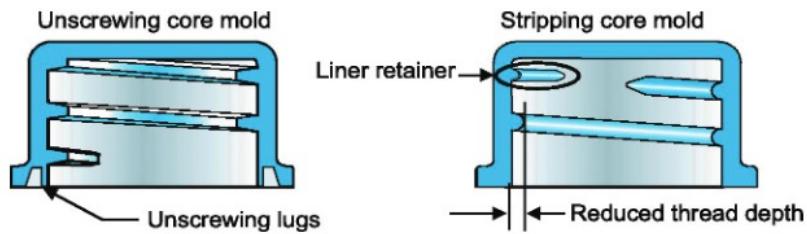
The ease with which thermoplastic can be formed into complex aesthetic and utility features allows closure designs not available with other materials.

The resilient nature of plastic has been taken advantage of to make press-fit closure bases that snap over an interference ridge on the container. (See Figure 13.12) In effect, the threaded finish and closure screw-cap become a single system or assembly. The capping operation is very fast since no cap threading or torquing is required on the production line.

An advantage of press-fit closures is that a TE seal with an attached pull ring can be molded across the finish fitment as shown by the dotted line in Figure 13.12, right. Similarly, a comb-like device can be molded into the bore of the fitment to provide more controllable pouring. The closure skirt also can be extended with a perforated ring that snaps over the bottle's neck ring to provide a breakaway TE feature.

## CLOSURE EJECTION

For any threaded closure, removal from the injection mold core can be a challenge. The resolution of this problem affects the closure's cost and performance. Removal of the closure from the mold can be done by:



**Figure 13.13**

Threads extend to the top in the unscrewed-core closure but can stop some distance away from the top of a stripped core closure.

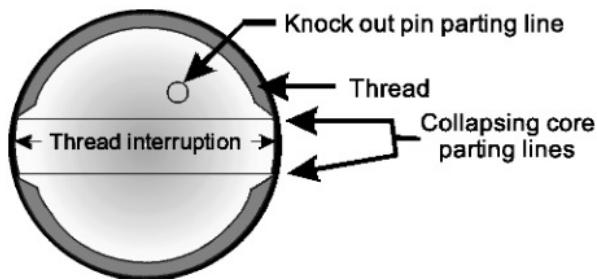
**Unscrewing the cores.** For a mold core to unscrew from the molded closure, the thread must continue all the way into the closure until it meets the top of the closure. An inserted liner cannot have a diameter significantly greater than the thread diameter (the closure's E dimension). This means that adhesive must be used to hold the liner in place. On the advantage side, the closure threads can be made quite deep, giving an unscrewed-core closure the best holding power. Of the three mold types, unscrewing core molds are the most expensive. Most unscrewing core closures can be recognized by a series of serrations or lugs around the perimeter of the skirt base that holds the closure and prevents it from rotating as the core is unscrewed. The difference can be seen in Figure 13.13.

**Stripping the closure off the core.** This requires that the plastic material itself have some recoverable elongation, so the closure can be stretched enough to override the mold threads. Secondly, the threads of stripped core closures are typically 25–30% shallower than for a similar closure made by the unscrewing core method. Advantages of using mold concepts that strip the closures off the cores include much faster cycle times and elimination of extra equipment. In addition, the molds are more cost-effective and durable, and stripping allows the placement of several liner-retaining ridges inside the closure. Liners are cut close to the closure's T diameter and held in place by the retainers. Unlike an adhesive-bonded liner, a retained liner is free to rotate within the closure. This can have significant implications on closure application and removal. The mechanism for pushing closures off the mold is simpler and more economical than unscrewing cores. Linerless closures need to be stripped from the mold because the sealing features don't allow the threads to reach the top panel.

**Collapsing core.** This option requires that the mold core be made of two halves that are able to collapse to a smaller diameter around a retractable center component, and thus be pulled straight out of the molded closure. To achieve this, the closure threads must be interrupted on opposite sides of the closure (so that the central component can be retracted); the interruption is for about 12 mm (1/2 in.). (See Figure 13.14) A knock-out pin helps push the closure off the cores. Collapsing cores have a cost advantage and can mold liner retainers similar to stripable core systems. A disadvantage is that there is some reduction in holding power since a thread portion is missing. Collapsing core systems tend to be used for large-diameter closures.

**Figure 13.14**

Inside view of a collapsed-core closure showing thread interruption and parting lines left by the retractable central mold component.



## CLOSURE APPLICATION

Compared to filling operations, capping operations are fairly straightforward. Closures typically are loaded into an unscrambler, hopper or waterfall sorter, which selects individual caps and feeds them in the correct orientation to a delivery chute. The selected closure slides down a ramp to meet the container. In most moderate-speed machines, the closure is presented at an angle to the moving container. The leading edge of the finish engages the closure lip and pulls it out of the delivery chute. (See Figure 13.15)

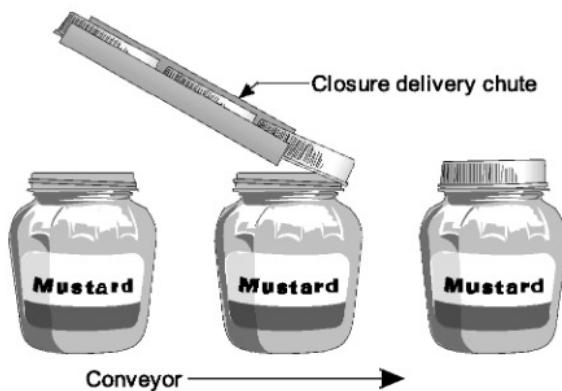
The container, with the closure resting on the finish, is indexed to a sealing or chucking station, where the appropriate mechanical action seals the closure to the container. This may be as simple as passing the closure between rotating resilient wheels that spin the closure on.

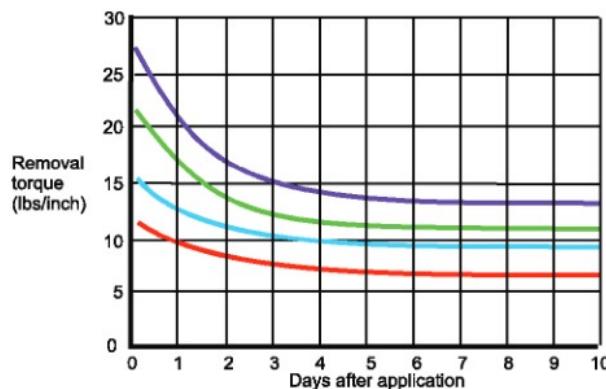
Most CR closures require a positive gripping chuck. On slower machines, this is done at one station while the container remains stationary throughout the closing motion. On moderate-speed (200–300 bottles per minute (bpm)) and high-speed (500–700 bpm) machines, the containers enter into a rotary sealing head with four, six, eight or more chucks or spindles. Container and chuck move together on rotary machines during the closing motion. An infeed timing screw and starwheel are required at each end of the rotary machine to ensure proper entry and exit.

Decorative or TE shrink neck bands usually are pre-prepared sleeves, which arrive in a magazine ready to be placed over the finish. After placement, the band is briefly exposed to heat to securely shrink it in place.

**Figure 13.15**

Typical arrangement for mating cap and bottle finish.





**Figure 13.16**  
Loss of torque and removal time. Data courtesy MAC Closures.

## Closure Torque

“Torque” is the resistance to application or removal of a threaded or lugged closure.

Thermoplastic closures on thermoplastic containers can suffer from considerable torque loss after application because of the viscoelastic flow (cold flow or creep) properties associated with these materials. (See Figure 13.16) This means that over time, the removal torque could be significantly less than the application torque. It is not unusual for a closure to lose about half of its torque in the first 24 hours, but each case and each package are different. Torque loss should be established for each closure system, with appropriate adjustments made to the application torque to compensate for loss.

- “Application torque,” or “static torque,” is a measure of the tightness to which the capping machine turns the closure. (See Table 13.4) Since application torque normally drops off, sometimes quite rapidly after application, removal torque for purposes of machine adjustment should be measured within the time limit specified by process control parameters.
- “Removal torque” is the force necessary to loosen and remove the closure. Removal torque normally is lower than application torque. The degree of torque reduction is a function of application torque, closure and container materials, geometries, tolerances and time.
- “Stripping torque” is the torque level that will cause the closure or bottle finish to distort to the point where the closure threads will override the matching closure or finish threads, resulting in component damage, loose caps or no seal.

Product on the finish threads can significantly increase or decrease application or removal torques. In some instances, the product may have a lubricating action; in others, the product may bond the closure to the finish.

Rigid glass containers and metal closures do not change or deform under normal stress. However, liner materials used in these systems will deform and set to new shapes. In extreme cases, pulp liners applied at high humidity will shrink upon drying, causing loose caps. Innerseals undergo significant dimensional change after induction sealing. While the container will not leak as long as the seal is intact, the closure itself can become quite loose.

**Table 13.4**

**Suggested application torques for some representative cap sizes. A rule of thumb is that the application torque in inch-pounds should be about half the closure's diameter in Newton-meters. Some newer designs may be compatible with lower application torques. Proper torque specs should be confirmed with the closure supplier to ensure optimum performance.**

Cap Size (mm)	Application Torque	
	Inch-pounds	Newton-meters
15	06–09	0.678–1.017
20	08–12	0.904–1.356
24	10–18	1.130–2.034
28	12–21	1.356–2.373
33	15–25	1.695–2.825
38	17–25	1.921–2.825
43	17–27	1.921–3.051
48	19–30	2.147–3.390
53	21–36	2.373–4.068
58	23–40	2.599–4.520
63	25–43	2.825–4.859
70	28–50	3.164–5.650
89	40–65	4.520–7.345
83	32–58	3.616–6.554
120	55–75	6.215–8.475

## Application Angle/DOR, Pull-Up Testing

Bottle and closure companies increasingly are making their products with special features used for seal-integrity testing. The rationale is that when the mark on the closure aligns with the mark on the bottle, the closure is properly tightened. Thus, the package is properly sealed. The marks are commonly known as indicator/pull-up marks.

Measuring the difference between these two marks is called the application angle test, also known as DOR (degrees of rotation), or pull-up, testing. The test measures the angle between the mark on the bottle and the mark on the closure. This measures the amount of rotation of the closure threads versus the bottle threads.

Historically, the test was completed manually using a gauge that measures degrees/angle of difference from the two marks. Recent developments in vision systems have automated this measurement by having a camera read the two marks and calculate the difference in between. This allows defective bottles to be removed from production.

Additional test methods for evaluating closures can be found on the ISBT website, [www.isbt.com/resources-guidelines-best-practices.asp](http://www.isbt.com/resources-guidelines-best-practices.asp). The *Plastic Bottle Closure Qualification Test Manual*, July 2019, PTC-00019 contains testing methodologies commonly used by suppliers and manufacturers. ISBT members have free access to the documents. Others may place an order by scrolling to “Download the Order Form.”

## TAMPER-EVIDENT (TE) CLOSURES

There is no officially recognized definition of what constitutes a TE closure. The Food and Drug Administration published 21 CFR 211.132, *Tamper-Evident Packaging Requirements for Over-the-counter Human Drug Products*. The FDA definition reads:

“Having an indicator or barrier to entry which, if breached or missing, can reasonably be expected to provide visible evidence to consumers that tampering has occurred.”

The ISBT has published a technical bulletin on *Tamper Evidence*, 2014, PTC-00015. It includes examples and discusses different types of TE closures and TE systems. The document also includes applicable rules and regulations about tamper evidence, including the above FDA reference and requirements of the Bureau of Alcohol, Tobacco, Firearms and Explosives.

Over-the-counter drug products, products accessible to the public at the point-of-sale, as well as contact lens solutions and some cosmetic products, are the products most affected. There must be a clear statement prominently placed so the consumer’s attention is drawn to the TE feature.

The main approach to preventing tampering involves the closure’s design. This fixation on the closure as a defense against tampering is common to both consumers and legislators. It is not something that bothers the tamperer. Package types that are not normally considered vulnerable have been violated at points other than the closure. Professional packagers should never use the term “tamper-proof,” because no practical package can thwart a determined tamperer.

A case in point is the Illinois person who laced 25 or so packages, including aseptic fruit drink packs, with arsenic, apparently using a syringe. In another incident, a tamperer managed to put a dose of cyanide into a conventional single-serving yogurt tub. In the final analysis, it is an often-ignored truth that we cannot protect ourselves entirely from the determined tamperer. It is also an ugly truth that the “urban terrorists” will always be with us.

Understanding the nature of the problem, we realize that many legislated measures will not stop a determined tamperer. TE packaging may make it more difficult, or even very difficult, for the would-be urban terrorist, but it rarely makes it impossible. This is not to say that such efforts should be abandoned. We should simply be aware that a TE closure does not guarantee our product against the determined tamperer.

Most tampering, fortunately, is simpler and is a nuisance rather than life-threatening. The casual extraction of a cookie while the parents are in another aisle, the insertion of a dead insect or exchanging salt for sugar are examples of this kind of activity. Properly sealed packages discourage this kind of impulse or nuisance tampering. In some instances, a TE design is a theft deterrent.

## TE Closure Systems

TE closures are important for products prone to attracting would-be tamperers. Worldwide, value-added closures—those proving tamper evidence, dispensing capabilities and child resistance—are prominently in use on packaged products. Consumers need closures that demonstrate that the package contents have not been interfered with or altered. Some packages, such as aerosols, are inherently TE or difficult to deliberately violate. Other packages need TE features added.

Typically, TE closure standards outside normal expectations have been guided by large consumer product manufacturers. These features can be grouped into 12 recognized categories:

- **Film wrappers.** A transparent film with a distinctive design is wrapped securely around a product or product container. The film must be cut or torn to open the container and remove the product.
- **Blister or strip packs.** Dosage units, such as pharmaceutical capsules or tablets, are individually sealed in clear plastic or foil. The individual compartment must be torn or broken to obtain the product.
- **Bubble packs.** The product and container are sealed in plastic and mounted in or on a display card. The plastic or paper must be torn or broken to remove the product.
- **Shrink seals and bands.** Bands or wrappers with a distinctive design are shrunk by heat to seal the closure and container union. The seal must be cut or torn to open the container and access the product.
- **Foil, paper or plastic pouches.** The product is enclosed in an individual pouch that must be torn or broken to obtain the product.
- **Bottle innerseals.** Paper or foil with a distinctive design is sealed to the mouth of a container under the closure. The seal must be torn or broken to open the container and remove the product.
- **Tape seals.** Paper or foil with a distinctive design is sealed over each carton flap or a bottle cap. The seal must be torn or broken to open the container and remove the product.
- **Break-away, or drop-band, closures.** The container is sealed by a plastic or metal cap that breaks when removed from the container and leaves part of the closure attached to the container. The cap must be broken to open the container and remove the product.
- **Sealed collapsible tubes.** The mouth of a tube is sealed, and the seal must be punctured to obtain the product.
- **Sealed carton.** All flaps of a carton are securely sealed and show visible damage after opening to remove the product.
- **Aerosol containers.** Aerosol containers are inherently TE.
- **Miscellaneous other systems.**

## CHILD-RESISTANT (CR) CLOSURES

As with TE closures, reality demands that CR packages never be referred to as “child-proof.” Any closure that is devised for reasonable adult use will be openable by some children—by accident if nothing else. Hence, the correct term: “child-resistant.”

CR closures are under the jurisdiction of the Consumer Product Safety Commission (CPSC). A list of substances covering drugs, household cleaning agents, pesticides and other products defines regulated substances. CR closures serve the safety concerns of the marketplace. Although CR closures certainly can be a nuisance, their effectiveness is readily apparent.

Since 1972 when CR closures were introduced, the incidence of accidental deaths has dropped 84% for all substances and 98% for aspirin alone.

Stringent test protocols define which closures can be classified as CR. These are described in 16 CFR 1700.20 in the United States. In Canada, the Canadian Standards Association administers such a program. In Europe, standards are overseen by the International Technical Centre for Bottling, known as Cetie. The protocols are similar but not identical.

Under CPSC requirements, the test to confirm child resistance is conducted with 200 children between the ages of 42 and 51 months. The children, working in pairs, are allowed 5 min to open the package. For those who are not able to open the package, a single nonverbal demonstration is given, and the children are allowed an additional 5 min. The demonstration’s purpose is to ensure the package cannot be opened by the child once the “trick” has been observed. True CR packages depend on the limited manual dexterity of a child. Typically, this involves two dissimilar simultaneous motions or actions. The CR effectiveness must be at least 85% without a demonstration and 80% after the demonstration.

The tests also incorporate a “senior-friendly” phase. A separate adult test, with 100 adults between the ages of 50 and 70, should produce a 90% or better success rate of opening the package. Opening instructions generally are designed into the closure’s crown or skirt, detailing a series of actions. Examples are: “line up the arrows and lift,” “push down and turn” or “squeeze and turn.”

## SPECIAL CLOSURES AND FUNCTIONS

### Corks

Cork was the original closure material. Until the early 1900s, it was the principal method of closing a bottle. Cork is the outer bark layer of the cork oak tree, grown principally in Spain, Portugal and North Africa. A tree produces usable cork every eight to 10 years, and supplies have become increasingly difficult to obtain in recent years. Cork provides an old-fashioned or nostalgic appearance, but being a natural material, its properties vary widely, and it often is the source of off-tastes. Many winemaking authorities concede that screw caps make a superior closure, but the oenophile tradition keeps the cork closure alive.

Nonetheless, there is a growing trend away from cork. In some instances, synthetic materials imitating cork, and still requiring a corkscrew to extract, are chosen.

Others are adopting conventional threaded closures, and it may be expected that eventually, most wines will be sold in screw-capped bottles.

## Decorative Applications and Styles

The package closure is a major element in developing a package persona. There are many closure design variations and persona treatments. Some closures used to develop these personas are old designs that, from a practical sense, are not very effective and often quite costly.

Sugar candy can be put in a stock jar with a stock screw-cap closure. As a presentation, it is not very inspiring. A circle of gingham cloth held over the screw cap with a string makes a tremendous difference. That touch adds visions of country cottages, and kindly, aproned grannies fixing a special treat for kids according to a secret recipe. This simple treatment increases the perceived value of the product.

The “lightning-style” closure was patented more than a century ago. (See Figure 13.17) Its ceramic plug, wire bail and rubber gasket are hopelessly complex, yet the closure is still commonly used on upscale products such as maple syrups and gourmet beers. A plastic version is available for those who can’t afford the ceramic plug.

The ground glass stopper is another traditional format that now sees limited use—mostly for perfumes, specialty cosmetic containers for bath salts and other upscale products.

Plug orifice closures often have an extended skirt around the bottle fitment component. (See Figure 13.20) The skirt normally is dimensioned to match the bottle profile. When fitted to an oval bottle, the closure will be a snap-fit rather than a threaded attachment. A means of ensuring that the closure skirt aligns with the oval bottle shape is part of the design.



**Figure 13.17**  
A lightning closure sealed (left) and opened (right).

Wax seals are seen on the front of bottles and over the closure itself. As with lightning stoppers, plastic-applied imitations are available. The seals serve primarily as decoration.

Overcaps are a way to decorate a package without having to change the original closure on the package. Overcaps are placed over and clip onto the original closures and can be applied by hand or inline during manufacturing. Overcaps provide the ability to change the look of the package with different colors, metallizing, embossing or shapes.

Laser printing makes it possible to print graphics on the top of the closure, easily switch designs and print multiple designs during a campaign. Laser coding often is used for promotional activities, whereby an alphanumeric code is inscribed on the underside of a closure. Consumers can use this UTC (under the closure) code to enter contests and gain credits toward prizes.

Lenticular designs are produced with a lenticular image, which is embossed into the closure material. This allows the consumer to see a different picture, as the viewing angle changes. Since this type of embossment is difficult to copy, it is a good anticounterfeiting measure and can be used on all types of closure designs.

## Multiple Lead Bottle Threads

A typical bottle thread might circle the finish until there is some overlap. Where a good seal is critical, the thread might continue until it has overlapped itself for a full 720 degrees. In such a design, a considerable amount of rotation is required before the closure is sufficiently tight.

Multiple lead threading (also called multiple pitch) uses short thread segments—for example, a thread may only be 45 degrees of the finish circumference—but there may be five or six such segments around the finish. The result is that there will be three or four thread overlaps at any given point on the circumference. This provides a very secure seal that requires a small rotation of the closure.

The dairy product bottle in Figure 13.18 has seven thread starts. The threads are very shallow, allowing for the low-density polyethylene closure to override the threads when it is pressed onto the bottle finish. The final rotation to produce a tight seal is less than 15 degrees. Strong engagement makes up for the shallow thread profile.



**Figure 13.18**

An example of a seven-lead finish.

Multiple thread finishes help prevent the closure from “cocking” during application to the bottle finish, providing more trouble-free running at the closure applicator.

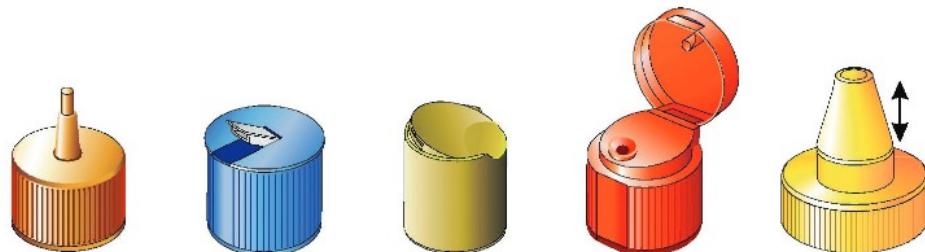
## Dispensers and Pumps

A variety of closures incorporate either a dispensing feature or a pump (See Figure 13.19, Figure 13.20 and Figure 13.21). There are far too many options to describe here. A visit to a retailer is a good way to become acquainted with the many choices available.

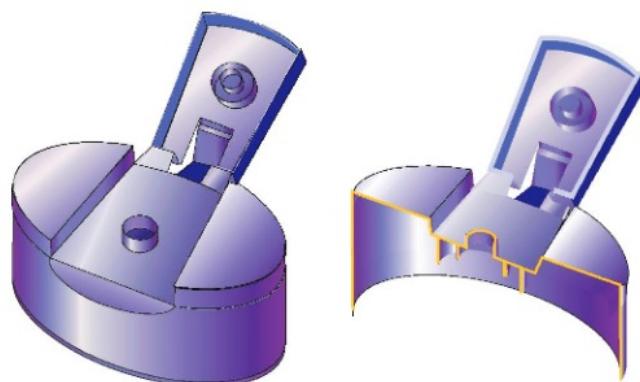
Dry-product dispensers usually incorporate a rotating or sliding plate that can be indexed over holes in the closure’s top surface. Large-pour openings and smaller sifter openings frequently are provided on the same closure.

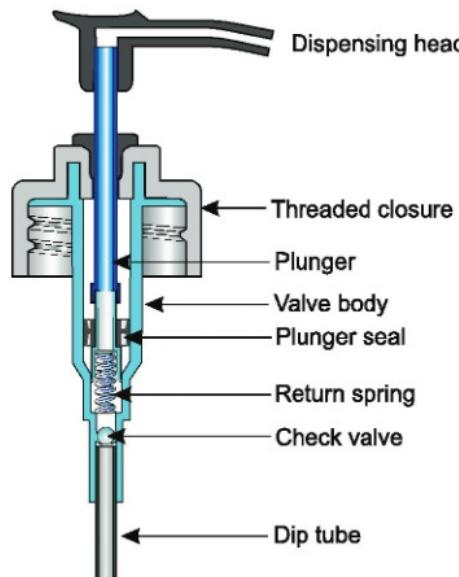
Among the earliest liquid dispensing formats was the snip-top with a spout or “nozzle” on its crown that was cut off. (See Figure 13.19, far left) This evolved into nozzle designs with captive caps, allowing consumers to use the container in one hand, opening the spout with their thumb. The push-pull dispenser, commonly used for kitchen detergents, has a movable device on the spout that opens when in an up position and closes when pushed down. Flip-spout dispensers have a spout that opens and closes as the spout is rotated into an up position. The disk-top variant is similar except that the dispensing passage is in a flat disk that is fitted into the top surface of the closure.

**Figure 13.19**  
Snip-top, flip-spout,  
disk top, plug orifice  
and push-pull liquid  
dispensers.



**Figure 13.20**  
A skirted dispensing  
closure and a cutaway  
view to show the finish  
fitment component.





**Figure 13.21**

A representative pump dispensing system. Geometries vary, but the basic action is similar for most pumps.

None of these dispensers is suitable for food products since the action of all of them would leave a small amount of product at the dispenser tip exposed to the atmosphere. The preferred plug-orifice dispenser has a fully topped flip-up action closure with a small plug that enters the container opening and returns most product to the container. (See Figure 13.20) Other dispensers operate by turning motions.

Plastic closures also form part of pump and spray dispensing systems for a wide variety of food, garden, automotive, household, pharmaceutical and cosmetic products. Pumps are selected according to the same criteria used in choosing dispensers.

- What is the product's viscosity?
- What volume needs to be dispensed with every activation?
- What has to come out: a fine mist, a patterned spray, a directed spray or an extruded bead?
- What is the desired dispensing direction?
- Are material compatibility issues anticipated?
- Should activation be with a finger button, a trigger or a palm?
- What are the size and shape of the container?

A representative pump is shown in Figure 13.21.

## Examples of Special Technical Functions

Some product categories require special functions in the closure:

- Dispensers for fluids, such as cooking oils, often have a comb-like piece inserted into the pouring orifice to even the flow. Another option relies on a thick silicone rubber insert across the closure opening. The silicone insert has an x-shaped slit across its face that stays closed and retains product even when the container is inverted. Slight pressure on the plastic bottle opens the slit to dispense product.
- Champagnes and highly-pressurized, cork-closed bottles have a wire basket or cage over the cork. Its function is twofold: It ensures that the cork does not eject prematurely, and it adds an element of heritage and authenticity.
- A jug containing a corrosive cleaning compound used in industrial washers has a closure that is not meant to come off. The jug is installed into the machine in an inverted position, and a water jet dissolves away a soluble disk that sits just behind a closure grating. The compound empties into the machine without ever being exposed.
- Sterility is of paramount importance when dealing with injectable solutions. Saline solution bottles are filled on the molding machine while still hot, and the top is pinched over, ensuring absolute sterility. What appears to be a closure has no sealing function. The purpose of the threaded cap is to break away the bottle finish at a deliberately weakened spot when the fluid is about to be used.
- Closures that must face a specific direction often are designed with a projection on the inside of the skirt that will stop closure rotation when this projection comes against a mating projection on the container finish. In this design, closure and container H and S dimensions are particularly critical. The closure liner or sealing system must be fully effective at a very specific degree of closure rotation.
- Flowback spout closures have become popular on many liquid laundry detergent bottles. This type of closure allows excess product to flow back into the bottle after it is dispensed using the cup portion of the closure.
- Aimed at reducing plastic litter, the tethered closure prevents the closure from separating from the bottle after it is opened. Various styles exist with hinge mechanisms and slit bands that allow the closure to be moved out of the way to drink but remain on the bottle for recycling.
- The versatility of plastics allows for an almost endless parade of convenience and aesthetic designs. Virtually all plastic closures can be designed with TE features. Measuring devices, spoons, daubers, brushes, sifters, pourers and flexible spouts have been developed. Closures having shapes ranging from automotive gears to zebras have been marketed to fascinate, entertain and, not incidentally, to inspire a purchase decision.

These are only a few examples of the ingenuity and multifunctional properties that can be built into a closure. Each of them offers important benefits to the consumer, and that is what good package design is all about.

## REVIEW QUESTIONS

- 1.** List 10 considerations critical to the design or selection of an effective closure system.
- 2.** What body has jurisdiction over industry finish and closure standards?
- 3.** On a bottle finish, what are the I, T, E, H, and S dimensions? What are the corresponding dimensions on a closure?
- 4.** Which thread style is preferred for plastic closures?
- 5.** How are closures designated?
- 6.** What is the advantage of a metal lug closure over a metal threaded closure?
- 7.** What are the disadvantages of a flip-spout type of dispensing closure?
- 8.** What are the advantages of press-on/twist-off closures?
- 9.** Why are liners necessary in metal closures? What is the purpose of the backing material in a lined closure?
- 10.** Explain how an induction innerseal works. What container or closure body materials would interfere with the creation of a seal?
- 11.** For what applications might you specify a closure made from a thermoset plastic?
- 12.** Most plastic closures are made from what material? By what process are they made?
- 13.** Where might we specify polyethylene as a closure material? Where might we specify polystyrene?
- 14.** What features and designs are available in plastic closures that cannot be made easily in metal?
- 15.** Define application torque, removal torque and stripping torque.
- 16.** Explain what might happen if a bottle's S dimension is too short or too long.
- 17.** Explain what will happen if the bottle's H dimension is too small.
- 18.** Why should the common term "tamper proof" not be used?
- 19.** List eight packaging systems that are considered to be tamper-evident.
- 20.** What is the design principle of a good child-resistant closure?
- 21.** What causes loss of torque in a plastic closure application?
- 22.** Where would a double-tight lid be used?
- 23.** Loss of torque would be higher when a polypropylene closure is applied to a polyethylene bottle than if a polypropylene closure is applied to a polypropylene bottle. Explain why.
- 24.** List three conditions or situations that contribute to loss of torque.
- 25.** What advantages are associated with multiple lead closures?

## Assignment

Develop a detailed document that describes a closure intended for a liquid pharmaceutical product requiring a high moisture and oxygen barrier. Explain the benefits gained through the closure's manufacturing process, materials and design detail. Explain the materials chosen and the dispensing requirements, as well as their benefits. You may make assumptions on size and fill volume.

## CONTENTS

### Introduction to Adhesives

Definitions, “adhesive” and “glue,” adhesion, cohesion, general adhesive properties.

### Theories of Adhesion

Mechanical adhesion theory, specific adhesion theory.

### Surface Treatment

Creating intimate contact, wetting out, nonpolar surfaces, treating low-polarity surfaces, flame treatment, corona discharge treatment, measuring dyne levels, interference layers, release coatings.

### Solidification

Adhesive solidification methods.

### Common Classes of Packaging Adhesives

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### Flexible Laminating Adhesives

Principle and applications, examples, solvent-based, waterborne and solventless adhesives, examples of products and constructions.

### Adhesive Application

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### Viscosity

Definition, molecular friction, viscosity and temperature, Newtonian fluids, other shear behaviors, thixotropy, viscosity units, measuring viscosity, viscosities of common materials.

### Adhesive Selection and Considerations

Chemistry of materials to be bonded; physical nature of the surfaces to be bonded; application method, machine speed, pot life; rate of assembly; application and end-use temperatures; humidity and water resistance; chemical resistance; food applications; color; specific density; pH (water-based adhesives only); solids or nonvolatiles content; storage life and storage conditions; diluting adhesives.

### Inspecting Bond Failures

Adhesive, cohesive, substrate failure modes.



## INTRODUCTION TO ADHESIVES

An adhesive is typically defined as a material that bonds substrates together by surface adhesion and internal cohesion. Although there are a variety of adhesives based on inorganic components, e.g., products like cement or sodium silicate (also known as water glass), the vast majority of adhesives in use today are organic-based.

There is no universal method of categorizing adhesives. Adhesives are variously classified by solidification method, polymer base, technology type or application category.

Strictly speaking, the term “glue” refers to a protein-based bonding substance obtained from animal hooves, bones and skins. Modern formulations, with few exceptions, are derived from natural polymers, such as starch, or are based on synthetic polymer classes. The term “glue” should not be used to refer to the natural and synthetic polymers used to join materials in packaging. Terms such as “gluing,” “glue-line” and “glue-bond” do not specifically identify a material and are acceptable, although “adhesive bonding” might be more technically correct.

Adhesion refers to the attraction or bond of one material to another material. Cohesion refers to the internal attraction or bond of a material’s molecules to each other. Adhesives with low cohesive strengths tend to flow (creep) under stress and thus not resist peeling and shearing stresses to which the bond may be subjected. Adhesive formulations must, in many instances, balance adhesive and cohesive properties. The distinction is also important when discussing bonding failure.

An adhesive’s properties determine how quickly a surface wets out and the final bond quality. The surface tension of an adhesive is related to its molecular polarity and determines how well it is attracted to a substrate’s surface. Viscosity affects machinability, how the adhesive flows out over the substrate, and, in the instance of porous substrates, the level to which an adhesive penetrates the substrate. Solids content or nonvolatile content, expressed as a percentage, refers to the actual amount of material left to form a bond after all solvents and carrier liquids have been removed.

Many different adhesives are used in what might be considered the “simple” process of labeling and packaging a product. Every substance has particular property and surface characteristics. Therefore, adhesive selection must consider these in conjunction with its end-use requirements.

This discussion concerns itself primarily with adhesives used to bond two surfaces together. However, the same principles govern the adhesion of printing inks to a substrate. An ink can be regarded as a pigmented adhesive.

## THEORIES OF ADHESION

Various theories explain why one substance bonds to another. However, it's commonly understood that adhesive bonds are the result of mechanical bonds and intermolecular interaction. Suffice to say that all theories relate to the nature and chemistry of the bonding surfaces.

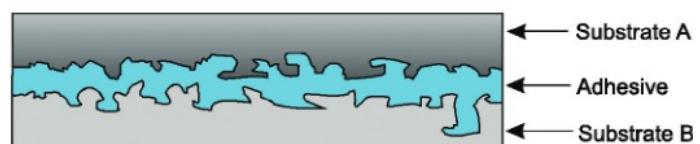
### Mechanical Adhesion Theory

Mechanical adhesion theory proposes that fluid adhesive flows into tiny surface irregularities. (See Figure 14.1) As the adhesive solidifies, bond strength is due solely to mechanical interlocking, therefore it can only be as strong as the cohesive strength of the adhesive or substrate.

When troubleshooting a bond failure between two paper surfaces, adhesive chemists will examine the failure surface under magnification for evidence of fiber tear. If there is no fiber tear, the adhesive has not penetrated the surface sufficiently to establish a mechanical bond. If adhesive is present on both substrate surfaces, then a good adhesive bond was formed to the paper surfaces and the failure is due to the low internal strength (cohesiveness) of the adhesive.

If there is significant fiber tear, the problem lies in the paper surface. One solution is deeper penetration of the surface to provide a more substantial bond. This can be done by using a more fluid adhesive or an adhesive that sets more slowly or by making glue-assist incisions in the paper surface.

Poorly bonded clay coatings frequently cause paper glue-line failures. In such failures, close examination reveals flecks of white clay on the adhesive failure surface. Incising is the usual way of penetrating the coated surface.



**Figure 14.1**

A mechanical adhesive bond occurs when adhesive flows into tiny surface irregularities in two surfaces.

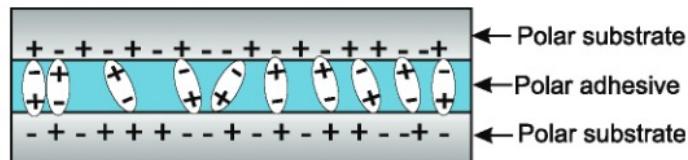
## Specific Adhesion Theory

The specific adhesion theory proposes that bonding takes place when minute regions of positive and negative charge are brought into intimate enough contact that they mutually attract one another, much as two magnets attract each other. The surface charges result primarily from dipole interaction, hydrogen bonding and Van der Waals forces. Their range of attraction is essentially in the molecular distance order. For interactions to occur, therefore, the two materials must be able to make intimate contact with each other. The different types of intermolecular interactions occur only at very small distances, of the order of typical atomic bond lengths. Types of intermolecular interactions are summarized in Table 14.1.

Two perfectly polished flat surfaces having surface polarities bond slightly by simply being brought together. Two new glass microscope slides are difficult to separate in tension because of this effect. The tensile bond between two dry microscope slides increases by wetting the surfaces with a trace amount of water. (See Figure 14.2) The mobile polar water molecules move to form bonds across places where the glass molecules are not quite aligned with their opposite charge as well as fill in minute surface irregularities. The number of polar bonds between the two plates increases significantly compared to dry glass. The union's tensile strength is substantially higher. This brings up several important observations:

**Table 14.1**  
**Types of intermolecular interactions.**

Type of Interaction	Energy (kJ/mol)	Basis of Attraction
<i>Bonding</i>		
Ionic	400–4000	Cation – Anion
Covalent	150–1100	Nuclei – Shared Electron Pair
Metallic	75–1000	Cations – Delocalized Electrons
<i>Non-Bonding</i>		
Ion – Dipole	40–600	Ion Charge – Dipole Charge
Hydrogen Bonding	10–40	Polar Bond to Hydrogen – Dipole Charge
Dipole – Dipole	5–25	Dipole Charges
Ion – Induced Dipole	3–15	Ion Charge – Polarizable Electrons
Dipole – Induced Dipole	2–10	Dipole Charge – Polarizable Electrons
Dispersion Forces	0.1–40	Interaction Between Polarizable Electrons

**Figure 14.2**

Specific adhesion depends on the attractions of minute surface polarities.

- The adhesive bond of a water molecule to glass is stronger than the cohesive bond of water molecules to each other. Increasing the water layer's thickness from a trace to a few millimeters reduces tensile strength, because now the bond separates by parting water molecules from each other (weak cohesive bonds) rather than by parting water molecules from the substrate (strong adhesive bonds). Some adhesives work the same way. Tensile strength may decrease with added adhesive, just as tensile strength decreases with added water in this example.
- Maximum bond strength occurs when the surfaces are perfectly covered with the amount of adhesive needed to contact and bridge the two surfaces. Less adhesive does not make use of the available bonding area. If the adhesive has low cohesive strength, excess adhesive will reduce the union's tensile strength. If the adhesive has high cohesive strength, added adhesive merely increases the union's thickness. In either case, more adhesive means higher costs.
- Tensile strength in the microscope slide/water example is high because—in trying to pull the slides apart—we are trying to simultaneously break millions of minute polar attractions. However, the shear strength of the same bond is quite weak, (that is, you can easily shift the slides sideways against each other) because here bonds are being formed and reformed. Shear strength can be increased by increasing adhesive viscosity. For example, corn syrup would give higher shear strength than water. The ultimate in viscosity is to have a material that won't flow, such as a solid.

## SURFACE TREATMENT

Minute quantities of surface contaminants can interfere with bond formation by preventing the adhesive from making intimate contact with the substrate. If the interfering layer is nonpolar, the adhesive releases from the interference layer. Conversely, the adhesive may make a strong bond with the interference layer, but the bond between the interference layer and the substrate may be weak. Interference layers can serve a useful purpose. A release paper, such as used to support pressure-sensitive labels, is a paper that has been coated with an interference layer (release coating) to minimize adhesion.

To make a good adhesive bond, it is necessary for the adhesive molecules to intimately contact the surface of the material to be bonded. The best contact is made by a material that will flow and conform to the substrate surface. So, an adhesive must be a liquid at the point of application and bond formation. Furthermore, the liquid and the surface must have characteristics conducive to the formation of a

chemical union. That is, the adhesive must be able to “wet out” the substrate. This means that the substrate surface should have some polarity and that the adhesive should be able to make contact with these polarities. Even microscopic layers of contaminating material prevent optimum bonding.

Many plastics, particularly polyethylene and polypropylene, have low-polarity surfaces, more properly described as having low surface energies. (See Table 14.2) This makes it difficult to apply and adhere printing inks, adhesives or functional coatings. Surface energies of such materials can be increased by chemically altering the surface using flame, corona discharge, plasma or chemical treatment. Flame treatment and corona discharge treatment are most commonly used in packaging.

Flame treatment passes the substrate through a gas flame that has been adjusted to have excess air. The hot oxygen in the flame is very reactive and reacts with the otherwise chemically-inert surface. Corona discharge creates a similar highly reactive atmosphere (ozone) using a high-frequency, high-voltage charge to ionize the air in contact with the plastic. Plastic films usually are treated with corona discharge since the application of direct flame would harm most films.

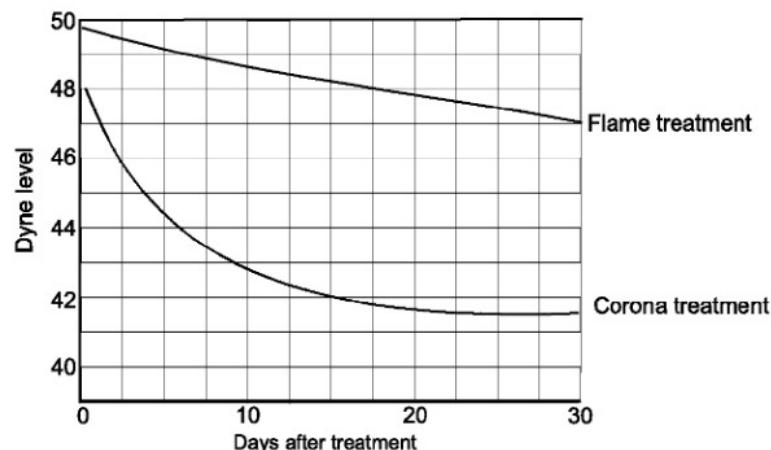
These treatments alter a material’s surface so that it has higher surface energy, therefore improving its ability to attract (be wetted out by) water or solvent-based inks, adhesives and coatings.

**Table 14.2**

**Surface energy (measured in dynes) for selected untreated polymers. Higher dyne levels indicate higher polarity. Metal and glass approach 100. The dyne level of water is 72. If a given solution wets the surface, its surface tension is lower than the substrate's surface energy; if instead, the wet adhesive rapidly forms beads, its surface tension exceeds the surface energy of the substrate. This result would produce a poor adhesion level between substrate and film.**

Material	Surface Tension (dynes)
Teflon	19
Polypropylene	29
Polyethylene	31
Polystyrene	33
Ionomers	33–37
Polyvinyl chloride	39
Polyvinylidene chloride	40
Polyethylene terephthalate	43
Polyamide	46

**Figure 14.3**  
Rates for polypropylene.  
(Source: Sherman  
Treaters.)

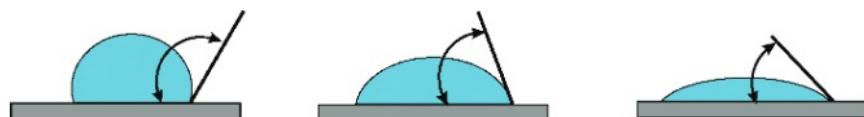


Flame and corona treatment is transitory, although flame treatment is somewhat more durable. (See Figure 14.3) Plastic materials slowly revert to their original condition unless printed, bonded or coated shortly after treatment. The reversion rate is highly variable depending on many factors, and it is not possible to assign a general “use before” rule for adhesive bonding.

Surface tension is measured in dynes (the force required to accelerate 1 gram by 1 centimeter (cm) per second<sup>2</sup>). To achieve good bonding, the dyne level of a surface should be about 10 dynes/cm higher than the surface tension of the wetting liquid. Generally, the dyne level of a surface should be 37 dynes/cm or higher to ensure adequate bonding of the adhesive material. However, each application should be independently evaluated. To assure spreading and wetting, the fluid adhesive should have a surface tension no higher than the substrate’s surface tension.

Surface tension can be determined by measuring the contact angle of a drop of distilled water with the test surface. (See Figure 14.4) Water will flow out in an even film (contact angle equals zero) over a perfectly wettable surface. At the other extreme, on superhydrophobic surfaces with nanostructures like the leaves of the lotus plant, the contact angles of water droplets exceed 150 degrees and roll off the surface without wetting it. This is referred to as the “lotus effect.” Contact angle goniometers measure the angle formed between a liquid drop and the substrate surface.

Another, simpler method is to use a series of solutions made up to have known dyne levels. These are applied to the test surface in increasing dyne increments until the solution at which an even film that will not bead up for at least 2 seconds is found. This is taken as the dyne level of that material.



**Figure 14.4**  
As a fluid becomes more attracted to the surface of a material, a drop of that fluid will move from having a large contact angle to a smaller contact angle. (Reference test method ASTM D5946.)

**Table 14.3**  
**Solutions with known dyne levels.**

Formamide Volume %	Ethyl Cellosolve Volume %	Surface Tension dynes/cm
0	100	30
2.5	97.5	31
10.5	89.5	32
19.0	81.0	33
26.5	73.5	34
35.0	65.0	35
42.5	57.5	36
48.5	51.5	37
54.0	46.0	38
59.0	41.0	39
63.5	36.5	40
67.5	32.5	41
71.5	28.5	42
74.7	25.3	43
78.0	22.0	44
80.3	19.7	45
83.0	17.0	46

ASTM International's Standard Test Method for Wetting Tension of Polyethylene and Polypropylene Films, ASTM D2578, describes the preparation of dyne solutions using mixtures of formamide and ethylene monoethyl ether (Cellosolve product from Union Carbide, now part of Dow Chemical Co.). DuPont's Victoria Pure Blue BO dye at about 0.03 % is added to make the liquid film clearly visible. A partial listing of ethyl Cellosolve and formamide mixtures and their respective surface tensions is given in Table 14.3.

## SOLIDIFICATION

It has been established that an adhesive must be:

- Polar to form chemical bonds with the substrate.
- Fluid so it can flow out and make intimate contact with (wet out) the substrate.

The final requirement of all adhesives is that the applied fluid be able to solidify to make the bond permanent. Table 14.4 lists the ways that adhesives solidify. It should be mentioned that an adhesive can undergo a combination of solidification

**Table 14.4**  
**Adhesive solidification methods.**

Technology Type	Solidification Method
Waterborne	Loss of water. Starch, dextrin and casein adhesives are common examples. A special category of waterborne adhesives is the emulsion types typified by "white glue," usually a polyvinyl acetate emulsion.
Solvent-based	Loss of solvent. Solid resins can be dissolved in various solvent combinations. Since solvents are volatile organic compounds (VOCs), their use is discouraged by many environmental, health and safety regulations. VOCs should be avoided if possible; however, certain resins can only be dissolved in solvents, and some substrates bond well only with solvent-based adhesives.
Hot melts	Loss of heat. Unlike the previous two categories, hot melts do not need a diluent or solvent that is removed during solidification. They are 100% solids. These adhesives are favored for high-speed production applications because of their fast setting time.
Reactive adhesives	Reactive adhesives usually are based on liquid prepolymers or special monomers that can be polymerized to a solid after application. There are various ways of initiating the chemical reactions leading to solidification. Some epoxies and polyesters require the mixing of two components or a component and a catalyst. Others are initiated by atmospheric oxygen, atmospheric moisture, heat or ultraviolet radiation.
Pressure-sensitives	These adhesives don't show a defined solidification process in physical or chemical hardening terms but can be described as liquids with very high viscosity and strong cohesion with permanent surface tack. Options include emulsion-, solvent-, hot-melt- or reactive-based.
Plastisols	Plastisol is a liquid physical mixture (suspension) of powdered thermoplastic polymer (polyvinyl chloride or acrylic) and plasticizer(s). When heated the plasticizer solvates the polyvinyl chloride and that yields a flexible plasticized product.

processes, and it might be difficult to classify those adhesives (e.g., waterborne, two-component, solvent-based ultraviolet-light-curable, reactive hot melts, etc.).

## COMMON CLASSES OF PACKAGING ADHESIVES

### Starch and Starch-Based Adhesives

Starch is a naturally occurring vegetable polymer usually extracted from the seeds, pitch and roots of corn, grains or potatoes. It forms a high-viscosity paste when 20–30% starch is mixed with water. High water content means that the adhesive requires a long drying time. On the plus side, starches are very economical.

Corrugated board manufacturing is the largest starch-based adhesive application. A starch/borax formula quickly gels by the application of heat.

The use of a starch-based adhesive is dependent on its basic characteristics. For example, in dispersions (a system of minute and discrete particles suspended in a liquid carrier), it forms films capable of covering surfaces and bonding substances together. To disperse the starch molecules or put them into a fluid state, water is used. Usually, solids are low, and a lot of water must be removed before a bond can be achieved. When the carrier (water) evaporates from the starch dispersion, a network of molecules is formed, thus producing a film that adheres to both surfaces of the substrates to form a bond.

Starch has limited solubility because of its high molecular weight. Starch molecular weight can be reduced and solubility increased by roasting in the presence of acids. The conversion can be stopped at any point, and generally, as conversion advances, adhesion qualities go down and possible solids content and tack properties go up. Glucose is totally depolymerized starch. Dextrin is a partly depolymerized starch with intermediate molecular weight. Dextrin dissolves more readily in water than starch and provides solids contents of 40% or 50%.

### Dextrins

Dextrins generally are roasted or converted starches, which have been cleaved by acids and heated to create shorter molecules. Dextrin adhesives have high tackiness, high solids, fair-to-good adhesion and are fast-drying. They can be modified further with borax, caustic, peptizers-salts, urea, calcium chloride or humectants. Processes also can be fine-tuned to enhance viscosity, softness, stability and speed of set.

Dextrins normally are classified as White Dextrins, Yellow Dextrins or British Gum Dextrins. Each type differs in conversion and percent solubility. In North America, most starches and dextrins are corn-based, either regular corn or waxy maize, which is a hybrid corn. In other countries, potato or tapioca starches typically are used.

Dextrins are economical and set faster than starches but still relatively slow-setting compared to synthetic systems. They are used where a long assembly time is an advantage, thus providing more setting time or where setting time is of no consequence (set-up boxes, bag making, tube winding). Starch-based adhesives have good adhesion to glass and metal but not to plastics. Mixing dextrins with borax (borated) improves tack and provides stable viscosities at moderate concentrations.

Alkaline treatment of starch produces jelly gums. These gums have exceptionally high tack and internal cohesion. At one time, jelly gum was a key labeling adhesive but now has largely been replaced by synthetics.

Starch and dextrin adhesives are thermoset polymers and have more heat resistance than most synthetic, thermoplastic polymer-based adhesives.

Water-based adhesives are commonly used for paper-bonding applications. The measure of a good bond is that it should tear the fiber when it is separated. However, care should be taken that this evaluation isn't done until the paper is thoroughly dried. Paper still wet from the adhesive's moisture always produces a fiber-tearing bond.

## **Casein Adhesives**

Casein adhesives are derived from the phosphoprotein in acidified milk. Properly formulated caseins have the unique property of having good cold-water resistance but of being rapidly hydrolyzed in aqueous caustic solutions. Refillable beverage bottles use casein-based adhesives so that the bottle retains its label when immersed in ice water, but the label is easily removed at the filling location. Some casein is used for foil laminating.

## **Animal Glue**

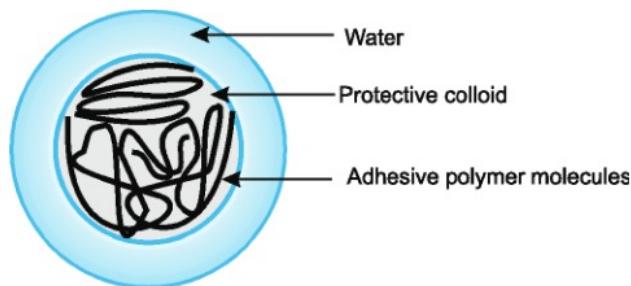
Animal glue, a collagen derivative, is a very tacky, protein-based glue used occasionally for set-up boxes and tube winding. Animal glue can be supplied as solid cakes, which are run at about 60°C (140°F). Once common, animal glues are rarely used now for packaging. However, their ready repulpability in warm water may make them an attractive choice for environmental reasons.

## **Synthetic Emulsions**

Large molecules give very strong bonds, but their solubility goes down as molecular weight goes up. The problem of having strong adhesive materials and high solids content is resolved by making an emulsion or dispersion of the adhesive in water. Synthetic emulsion and dispersion adhesives are based on polymers such as polyvinyl acetates, acrylates and maleates, which in themselves are not water-soluble. However, when fine particles of the polymer are surrounded by a protective colloid such as polyvinyl alcohol, the resulting product can be suspended in water.

A single emulsion micelle consists of a polymer unit surrounded by a protective colloid and the whole surrounded by water. (See Figure 14.5) If the water is reduced beyond a critical point, the micelles can no longer be completely encapsulated, and the suspension "breaks." When this occurs, individual polymer units combine with others to form an adhesive film.

Emulsions are in the 40–70% solids content range, and this alone would provide a faster drying time than a starch or dextrin. When an emulsion breaks, a partial or green bond forms almost immediately. (See Figure 14.6) Emulsions can break in a



**Figure 14.5**  
An emulsion micelle.

few seconds, and the green bond is able to hold labels or carton glue flaps in place. Bond strength increases slowly as the water evaporates.

The polymers used in emulsion and dispersion adhesives can be of relatively high molecular weight, providing bonds with good performance under high stress and good heat resistance. Since the polymer molecule is encapsulated in the micelle, there are no problems with achieving a high solids content while maintaining reasonable viscosity. Emulsion adhesives have exceptionally broad formulation possibilities. For example, they can be made water-resistant or re-moistenable.

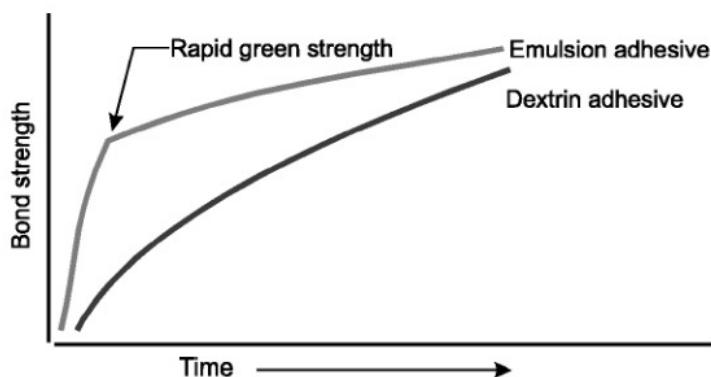
Freezing, pH shifts and chemical interference with the emulsifier (polyvinyl alcohol is typical) can upset the emulsion balance, resulting in a coagulated lump of the bonding resin.

Water-based adhesives are easy to use and clean up. They are economical and used extensively in all forms of paper packaging applications, from cartoning to labeling. Water-based adhesives may not perform well on plastic substrates.

## Hot Melts

Hot-melt adhesives are 100% solids and applied in molten form. Ethylene-vinyl acetate is the most common base resin used in formulating hot-melt adhesives. However, with the development of metallocene-based polyolefins, hot melts based on these polymers see an increasing penetration into the market, especially where high thermal stability, wide use temperature range or difficult-to-bond substrates are a concern.

**Figure 14.6**  
Bond development for emulsion and starch-type adhesives.



The base polymers usually are blended with other materials, such as waxes and tackifiers. Low molecular weight polymers for low viscosity are desired for most hot-melt formulations. The polymer contributes the majority of the structural strength to the adhesive. The wax is important for viscosity control and adjustment of open time and set speed, whereas the tackifier's main tasks are to improve hot tack and the viscosity of the formulation. Other materials influence melt temperature, melt rate, wetting behavior or other application-related parameters. Added colorants make the application more visible.

Like many organic materials, hot-melt adhesives can degrade with extended heating. Prolonged heating initiates self-perpetuating free radical degradation processes. Initiation is encouraged by the presence of external foreign material and char from the degradation process itself. The process initiates the joining and growth of lower molecular weight entities into higher molecular weight species that eventually become insoluble in the melt. This eventually leads to charring. Char can clog delivery systems and plug dispensing orifices. Antioxidants and heat stabilizers are important hot-melt components.

Most general-purpose hot melts are applied at about 177°C (350°F). Formulations applying as low as 121°C (250°F) are available. The defined melting point of hot melts can limit their application. Few packaging hot melts are reliable above 70°C (158°F), although formulations based on polyamides and polyurethanes have fairly good performance at elevated temperatures, but at a higher cost and with other limitations specific to their chemistry and physical properties.

The substrate must be able to tolerate the application temperature without warping or shrinking. Hot melts may not be suitable for items coming out of or going into thermal processing. Conversely, an economical hot melt may have a significant amount of wax diluent. Such an adhesive could become quite brittle in freezer conditions.

Since removal of heat can be done much faster than removal of water, hot melts set much faster than aqueous adhesives. This feature and their 100% solids content have made them the adhesive of choice for many high-speed packaging applications. Hot melts can be extruded as a fairly substantial bead, thus enabling them to bridge gaps. Hot melts sometimes are preapplied and then reactivated by applying heat. Conventional hot melts are, by nature, water-resistant and can be formulated for many specialty applications, including thermosetting and pressure-sensitive formulas.

Hot-melt adhesive bonds are best tested the next day or several days after forming. Adhesive polymer resins sometimes crystallize with time, and this can seriously affect bond strength.

Ring and ball (R&B) softening points often are used to characterize hot melts. The "R&B softening point" is the temperature at which the hot melt softens enough for a metal ball of a specified size and mass to drop through it.

Hot melts come in a variety of solid shapes. Slats, pillows, wafers and chips are the most common forms. Pellets are used in automated feeding systems and extruders. They eliminate "bridging" (forming solid masses above the melt pool) in premelters and can feed into small hot-melt pot openings.

Hot-melt adhesives are a paper recycling concern. The European Paper Recycling Council ([www.paperforrecycling.eu](http://www.paperforrecycling.eu)) helps end users determine whether an adhesive will be compatible with the recycling process. It outlines test methodology in *Assessment of Printed Product Recyclability, Scorecard for the Removability of Ad-*

*hesive Applications* and exempts non-water-soluble or non-redispersible hot melts from testing if the adhesive meets the following conditions:

- Minimum 68°C softening temperature (according to R&B).
- Minimum layer thickness of 120 micrometers (non reactive adhesive).
- Minimum layer thickness of 60 micrometers (reactive adhesive).
- Minimum 1.6 millimeters horizontal dimension of the application (in either direction).

## Lacquer Adhesives

The term “lacquer adhesives” generally applies to any solvent-based adhesive. These adhesives are used most often by converters in coating and laminating operations, particularly with plastic substrates. They dry much faster than waterborne systems. In addition, there is considerable formulation latitude. However, due to environmental, health and safety concerns regarding the use of organic solvents, there is additional scrutiny of solvent-based adhesive systems.

Laminating lacquers are applied to the primary substrate and immediately oven-dried to leave a pressure-sensitive surface to which the next, secondary laminate component is nipped. If both laminate components are impermeable, it is particularly important to drive off all solvents. Residue solvents will evaporate, and since they have no place to go, will blister the laminate structure.

## Pressure-Sensitive Adhesives

Pressure-sensitive adhesives (PSAs) are mostly based on one of two elastomeric polymer classes: acrylics and rubber/resin blends. PSAs typically are used in tapes and labels consisting of facestock, adhesive and release liner. Alternatively, the PSA can be applied directly in a laminating process or as transfer tape.

PSA formulations provide a strong bond and exhibit very good initial tack to hold the label on the container or other substrates and prevent curl-back. The ingredients normally used in making PSAs include:

- Resin or rubber base.
- Tackifiers.
- Plasticizers.
- Fillers.
- Antioxidants.
- Carrier, if pressure-sensitive is solvent or waterborne.

This combination of ingredients delivers the following desired results:

- Wetting ability or quick stick (the ability of an adhesive to wet the surface of the container or other substances with little external pressure).

- Specific adhesion (fiber tear or peel bond).
- Cohesive strength (cohesiveness greater than the adhesiveness to prevent separating the adhesive from the substrate and facestock).
- Even adhesive distribution or film thickness.
- Ability to avoid block and release from the liner with no problems.

The surface of a PSA is classed as a very high-viscosity liquid, and it is this feature that provides the instant bonding characteristic. Extremely soft PSAs bond to virtually any surface; however, their cohesive strength likely will be too low for most practical uses.

Acrylic formulations typically are based on acrylic acid ester monomers with appropriate comonomers. The balance of cohesive strength (internal strength, resistance to creep) and adhesive ability (rapid wetting of a second substrate) is achieved by monomer selection and ratios and degree of polymerization. The more highly polymerized grades have higher cohesion but lower adhesion. Acrylic-based systems usually perform better at low temperatures than rubber/resin blends.

Rubber/resin blends balance adhesion and cohesion properties by the choice of base rubber/resin combinations, their molecular weights and the type and amount of added tackifiers. Low cohesive strength formulations sometimes are used in peelable and resealable packages.

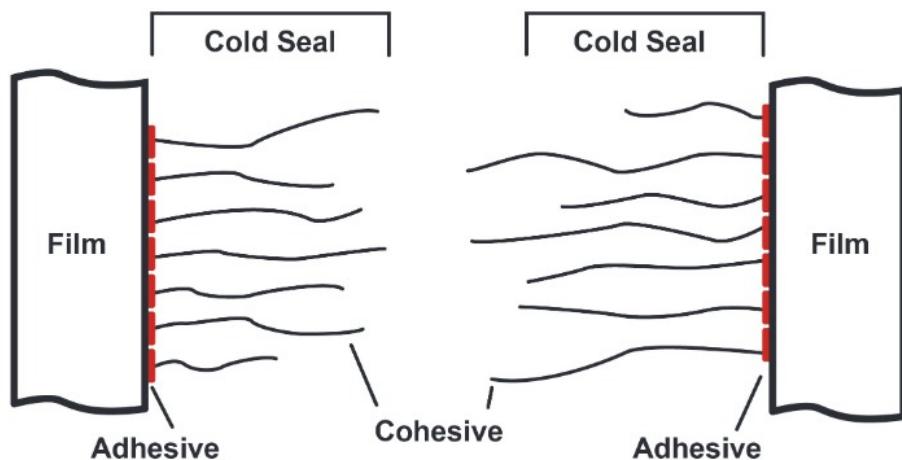
In addition to the base formulation, a curing or cross-linking step can be used to increase molecular weight after the coating step. This step can be self-initiated after the solvent is removed or activated by direct heat or another energy source.

PSAs frequently are used in conjunction with a release paper to manufacture pressure-sensitive labelstock. The base is a heavily calendered paper that has been coated with a silicone or fluoropolymer release (anti-adhesive) coating. A PSA is applied to the release surface, and a paper label stock is nipped against the adhesive. When peeled away, the adhesive binds to the facing paper and comes away from the release coating.

Though more expensive than regular labels, pressure-sensitive labels eliminate the need for glue stations at the labeling point. Furthermore, roll-formed labels are easier to count and track than loose labels. These features are of special importance to the pharmaceutical and other regulated industries. Pressure-sensitive labels, made in roll or fanfold form, also offer faster changeovers between products.

## Cold-Seal Adhesives

Cold-seal adhesive coatings, a type of co-adhesive, are composed of a physical mixture of dissimilar emulsions of a waterborne adhesive and a cohesive portion. "Co-adhesive" simply means that the cohesive component has a greater tendency to stick to itself rather than to other surfaces. The cohesive component of a cold-seal adhesive usually is based on natural rubber latex, and the cohesive components intertwine under pressure to give bonding. The adhesive component gives anchorage of the overall coating to the rigid substrate. (See Figure 14.7)



**Figure 14.7**

Cold-seal adhesives consist of an adhesive component that adheres to the film and a cohesive component that readily bonds to itself via chain entanglement when exposed to pressure.

The adhesive formulation is preapplied, typically to a flexible wrapping material, by the printer or laminator. When the wrapping material is wound into rolls, the adhesive face contacts only the front side of the wrap. When a wrap or pouch is produced, two adhesive-coated surfaces are brought together, and a bond forms immediately.

Cold seals originally were developed for bonding plastic-based wrappers for chocolate bars, where chocolate's low melting point precludes heat sealing. The applications for cold-seal adhesives have expanded to other flexible packaging applications where the instant bond-on-contact feature enables faster machine speeds without the need of heat that may damage temperature-sensitive contents, such as ice cream and frozen confectionery bars.

## FLEXIBLE LAMINATING ADHESIVES

A flexible laminating adhesive bonds two or more continuous webs together to form a laminate, which is used by packagers to form packages for their products. There are many types of flexible laminating adhesives, including:

- Solvent-borne—one- and two-part polyurethanes, polyesters, rubber solutions.
- Waterborne—acrylics, polyurethanes.
- 100% solids (solvent free)—polyurethanes (generally applied by meter mix equipment).
- Ultraviolet (UV)-light/electron-beam-curable—100% solids. Radiation-curable polyurethanes; some of these products will be formulated with UV photoinitiators.

The finished laminate used by the packager contains the adhesive that has been applied by the laminate producer to one of the substrates, dried, combined with a second substrate, rewound and cured. The adhesive used by the laminate producer may be, as previously mentioned, solvent-borne, waterborne or 100% solids (including radiation-curable types). In the case of polyurethane adhesive, the most widely used type, products include:

- One-part, solvent-borne, isocyanate-based moisture-cure adhesive.
- Two-part, solvent-borne, isocyanate-prepolymer/polyol adhesive.
- Two-part, waterborne, polyurethane dispersion/crosslinker.
- Two-part, solventless (100% solids) isocyanate prepolymer/polyol adhesive.

Solvent-borne laminating adhesives have dominated the industry for many decades, but are being replaced slowly by waterborne or solventless options, particularly as the latter achieve performance levels similar to the solvent-borne types. Great strides have been made in recent years in both waterborne and solventless adhesive technology.

Examples of end-use applications for adhesive-laminated packages include:

Snack foods	Condiment packs
Household goods	Boil-in-bag
Candy bar wraps	Sterilizable medical pouches
Frozen foods	Pharmaceutical packs
Meat and cheese packages	Retort packages
Coffee pouches	Aseptic packages

Among the concerns that the packager (user) of the lamination must consider include:

Clarity and appearance of the lamination	Heat sealability
Ink lifting	Adhesive migration
Retained solvent	Compatibility of the product with the lamination and the adhesive
Odor	Aging
Bond strength-adhesion values	

The purchaser is urged to work closely with the lamination supplier, specifying and agreeing to requirements such as those previously mentioned, test methods (examples: peel strength, heat seal, solvent retention, end-use testing, etc.) and any in-plant company requirements.

There is a trend toward waterborne and solventless adhesives in the flexible laminating market, as well as toward solventless adhesives that are radiation-curable.

## ADHESIVE APPLICATION

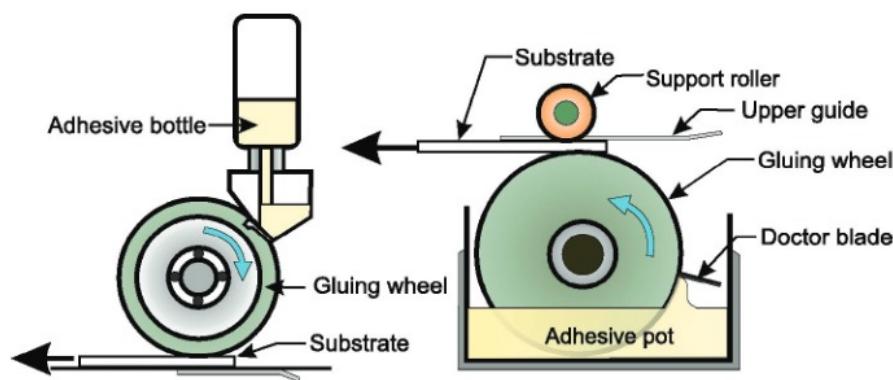
Adhesives come in diverse chemistries in various forms for many uses. Therefore, it is not surprising to encounter numerous application techniques and options. The selection of a specific application method or combination of methods is related to many factors, including the adhesive type, application amount, substrate geometry, line speed, viscosity, etc. Principal adhesive application methods include:

**Hand application.** The most basic way of applying an adhesive is by hand. In the case of waterborne or solvent-based adhesives, a brush or manual dispenser can be used as simple tools, but manual hot-melt guns and glue sticks also are reliable options.

**Roll applicators.** Roll or wheel applicators use a wheel rotating in a reservoir of adhesive. (See Figure 14.8) The adhesive can be metered in several ways, including removing excess with a doctor blade or passing between metering rolls. Shaped rubber plates or engraved rolls can be used to apply adhesives in patterns. At high speeds, roll applicators tend to throw off adhesive. Cleanliness is hard to maintain with open reservoirs.

**Gravure roll.** This application method is common in laminating operations. Gravure application is the most accurate application method, but it only can be used with relatively low-viscosity adhesives.

**Nozzle applicators.** In this technique, pumps move adhesive from the reservoir to a valved dispensing head. The valves are triggered with timing devices, which control the flow of adhesive to the dispensing head. The dispensing head can have several orifices, depending on the adhesive pattern. More sophisticated designs can be programmed electronically to produce various lay-down patterns.



**Figure 14.8**

Typical roller-type adhesive applicators apply a continuous line of adhesive. A second roll bearing a flexible plate configured to the desired design, such as in flexographic printing, would be added for placing an adhesive pattern.

Nozzle applicators are the most common method of applying hot-melt adhesives. Piston pump types are simple but have a slight flow interruption (wink) with each cycle. Gear pumps are more complex but provide a steady flow. Hot-melt extrusion systems can be programmed to provide a wide range of patterned applications.

**Extrusion.** Adhesives with a very high viscosity, where a normal flow of the material cannot be generated by simple pump action, may need to be applied via an extrusion process.

**Spray applicators.** Unlike extrusion applicators, spray applicators do not make contact with the substrate. As the adhesive leaves the glue-head, it is dispersed into minute particles and carried by air to the substrate. Spraying requires a lower-viscosity adhesive.

## VISCOSITY

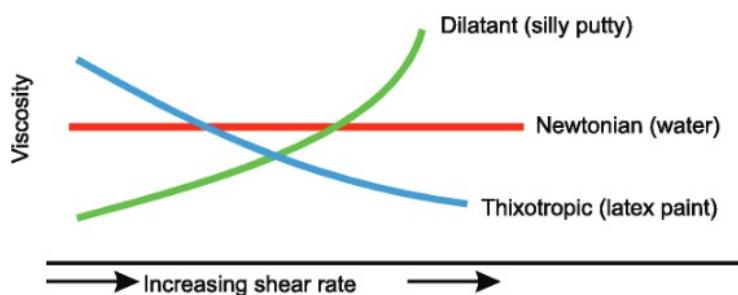
Viscosity is a measure of the resistance of a fluid that is being deformed by either shear or tensile stress. In everyday terms (and for fluids only), viscosity is “thickness” or “internal friction.” Thus, water is “thin,” having a lower viscosity, while honey is “thick,” having a higher viscosity. Put simply, the less viscous the fluid, the greater its ease of movement (fluidity). The study of flowing matter is known as rheology, which includes viscosity and related concepts. The viscosity of some common fluids is shown in Table 14.5.

When a liquid moves across a surface, the part of the fluid that is in contact with the stationary surface tends to “drag.” The degree of drag depends on the energy characteristics of the surface and the fluid. The molecules farther above the stationary surface want to move faster but are held back by the slower-moving molecules

**Table 14.5**  
**Typical viscosities at 20°C (68°F) in mPa × s\*.**

Fluid	Viscosity
Gasoline	0.65
Water	1.00
Cream	10
Olive oil	100
Honey	100,000
Pitch	10,000,000

*millipascal seconds. (See section, Measuring Viscosity, below)*



**Figure 14.9**  
Viscosity behavior and shear for various non-Newtonian fluids.

closer to the surface. Finally, farthest from the stationary surface, the only hindrance to flow is the internal friction between molecules that are trying to move at different speeds relative to one another.

The degree of molecular friction that opposes fluid movement depends on the nature of the molecules. For example, molecules that are large, long or highly concentrated cannot readily move from one place to another.

Molecules in liquids interact more slowly at lower temperatures; therefore, liquids are more viscous at lower temperatures.

The slower the molecules interact, the more the fluid resists changing shape (flowing), and the more viscous it is. The energy needed to overcome internal friction and keep a fluid moving is the coefficient of viscosity. Flow, or movement of different parts of the fluid, causes the stress or shear that creates molecular friction or strain. For many fluids, the shear stress (resistance to movement) is directly proportional to the shear rate (the rate at which we stir or try to move the fluid.) Such fluids are called Newtonian fluids.

For Newtonian fluids, the amount of shear and the stress (the resistance to flow) change at constant rates relative to each other. With non-Newtonian fluids, the proportion between shear stress and shear strain is not a constant. Water, simple organic liquids, gases and dilute suspensions are Newtonian fluids. More concentrated suspensions and emulsions are non-Newtonian.

Non-Newtonian behavior can be of several types. (See Figure 14.9) Dilatant liquids show an increase in viscosity with increased shear. Silly Putty, sold as an amusement, exhibits dilatancy. If the shear rate is low, the material flows gradually, just like thick syrup. However, if the putty is impacted (high shear), it shatters with sharp, angular edges reminiscent of a brittle fracture. At the moment of impact, it is, for all practical purposes, a solid. Dilatant behavior is not common and exists mostly in highly filled dispersions.

Pseudoplasticity and thixotropy are the opposite of dilatant behavior. The viscosity of a pseudoplastic decreases as the rate of shear increases. Thixotropes also start as viscous fluids or semi-solids, but the change in viscosity when stirred is time-dependent. Even at a constant low-level shear, their viscosity decreases.

Many adhesives, paints and inks become thinner when stirred and revert to their undisturbed viscosity when the shear is removed.

The viscosities of adhesives, inks, coatings and other fluids used in packaging are important. Few are Newtonian; many exhibit varying degrees of pseudoplasticity or thixotropy. Since the fluids experience shear as they are pumped, rolled and applied, it is important to know their viscosity under use conditions.

Each machine condition has an ideal viscosity associated with it. Changing conditions may make a fluid unsuitable for an application. An adhesive that applies well at one application speed may apply poorly at another because of a shift in viscosity.

## Measuring Viscosity

Viscosity is measured with various types of viscometers and rheometers. A rheometer is used for fluids that cannot be defined by a single value of viscosity and therefore require more parameters to be set and measured than is the case for a viscometer. Close temperature control of the fluid is essential to accurate measurements, particularly in materials like lubricants, whose viscosity can double with a change of only 5°C.

The common unit for the dynamic and shear viscosity is the poise (P) and centipoise (cps), named after Poiseulle, a pioneer in rheology. The correct SI unit is the pascal second ( $\text{Pa} \times \text{s}$ ). For conversion,

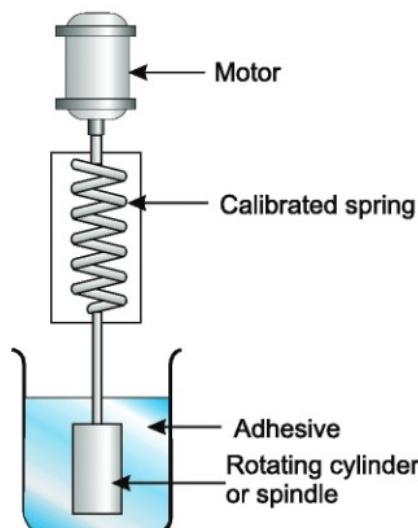
$$10 \text{ poise} = 1 \text{ Pa} \times \text{s}$$

$$1 \text{ centipoise (cps)} = 1 \text{ mPa} \times \text{s}$$

There are many ways to assign a value to viscosity. Some are empirical; others are more exacting. Some industries have specific methods. The following are examples of such methods.

Rotating-cylinder instruments are based on the principle that a cylinder rotated in a liquid will experience a drag proportional to the liquid viscosity. By connecting the spindle through a spring and a pointer, the fluid's viscosity can be measured. (See Figure 14.10)

The most common rotating-cylinder instrument is the Brookfield viscometer. Brookfield viscometers are supplied with numbered spindles ranging from a straight rod through rods with a disk or a cylinder. A second series of spindles is used for awkward materials, such as pastes, and consists of a rod with a crossbar.



**Figure 14.10**  
Operating principle of a rotating-spindle viscometer.

A typical Brookfield viscometer has several speeds or shear rates. Coupled with the spindle selection, it can measure virtually the entire common viscosity range and easily characterize non-Newtonian behavior. Temperature-controlled sample cups permit the Brookfield unit to be used for measuring hot-melt viscosities at use temperature.

Most adhesives are rated with a Brookfield viscometer. Always check that the model, temperature, spindle and revolutions per minute are the same when comparing viscosity.

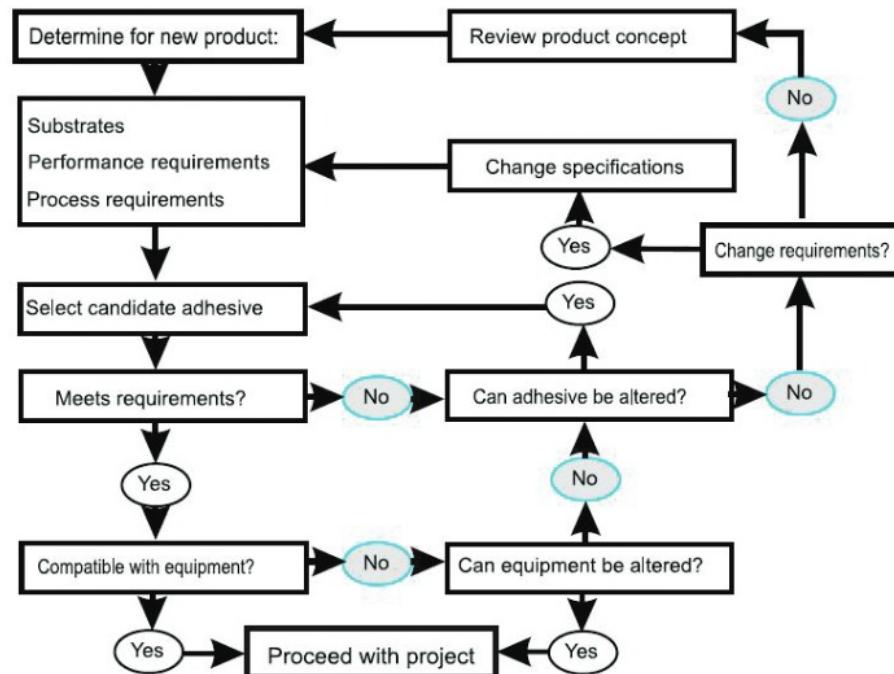
Cone-and-plate viscometers (e.g., the Haake viscometer) consist of a stationary plate and a cone with a small angle. The fluid is sheared between the two, and the resulting resistance to rotation is measured. Cone-and-plate viscometers have the advantage of requiring a small sample and being capable of high absolute shear rates.

Flow-cup or efflux methods are one of the simplest techniques for measuring viscosity and based on measuring the time for a standard fluid volume to flow through a standard orifice diameter. There are many flow-cup geometries, usually named after the originator (Ford cup, Zahn cup, BS cup, etc.). Since the practical viscosity range available for any orifice size is narrow, the cups usually come in sets, with larger orifices for more viscous liquids. Flow-cup viscosity measurements are easy and convenient to make but are restricted to low-viscosity fluids. The efflux time also can be converted to kinematic viscosities (centistokes, cSt) through the conversion equations. The kinematic viscosity is the dynamic viscosity divided by the fluid's density.

## ADHESIVE SELECTION AND CONSIDERATIONS

Adhesive selection always should be done in close consultation with an adhesive supplier. Figure 14.11 shows a general model for selecting adhesives.

**Figure 14.11**  
The adhesive selection process.



## Chemistry of Materials to Be Bonded

The chemical nature and the properties of the two materials to be joined are the single most important factors when selecting an adhesive. Do not be swayed by similar appearances or similar materials. Every adhesive application must be verified by testing. Special treatments or primers may be needed to achieve good adhesion.

## Physical Nature of the Surfaces to Be Bonded

The physical nature of the surfaces to be bonded may dictate certain adhesive choices. For example, recycled paper has short, closely matted fibers and a surface that is not very porous. A low-solids, low-viscosity adhesive could be used since it will not be readily absorbed into the fiberboard. A kraft stock, on the other hand, has a long-fiber, open structure with a porous but nonabsorbent surface. The low-solids, low-viscosity adhesive will disappear into the paper substrate in such an application. A high-solids, high-viscosity adhesive might be a better choice.

Flexible and extensible substrates need flexible and extensible adhesives; otherwise, the adhesive will break loose when the substrate flexes or stretches.

## Application Method, Machine Speed, Pot Life

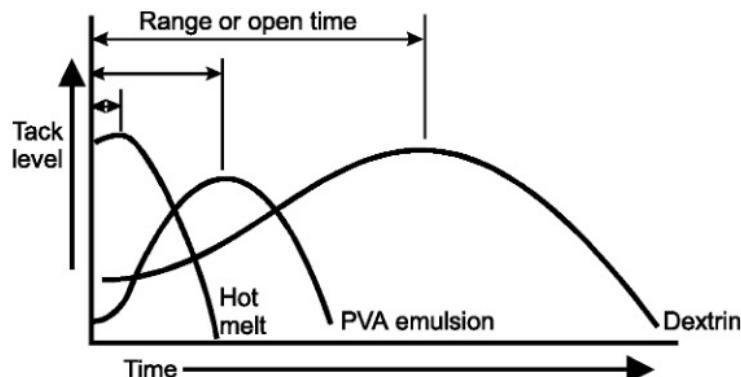
Application method, machine speed and pot life are interrelated and basically describe the manufacturing method. The adhesive's viscosity characteristics must suit the application method and the substrate. "Pot life" refers to the stability of the adhesive in the machine. Reactive thermosets in particular must have a pot life that will preclude their setting up in the machine during normal operations.

Drying time, as opposed to setting speed, may be important in applications where there are frequent machine stoppages. Slower-drying adhesives will be less likely to foul the machine.

## Rate of Assembly

"Open time" describes the time between adhesive application and the time at which the adhesive has set or dried to the point where it has lost tack or lost the ability to form a bond at the mating surface. An emulsion adhesive that breaks in 7 seconds (sec) may not be suitable for an application where there are 10 sec between adhesive application and part assembly. Similarly, for hot melts, the parts must be joined before the hot melt has cooled to the point where it is incapable of properly wetting the mating surface.

For wet adhesives, the development of tack and the period over which a successful bond can be made is sometimes referred to as the "tack and range." In Figure 14.12, neither the polyvinyl acetate (PVA) emulsion nor the dextrin has much tack at the beginning. The PVA emulsion rapidly develops tack when the emulsion breaks. The dextrin takes longer to develop tack and has a longer tack period in which assembly can be done. It also dries slower. Open time for each adhesive would be the time to peak tack level.

**Figure 14.12**

"Open time" or "tack and range" for three adhesive types.

In situations where bonding is performed at such high speeds that the adhesive does not have time to set completely, the adhesive often must restrain other forces (such as spring-back on a folding carton) when the assembled piece leaves the machine. This requires high wet tack or rapid green strength development.

In any application there is always an optimum adhesive film thickness. Adhesives that are particularly sensitive to variations in application rate should have more precise methods of metering and application.

## Application and End-Use Temperatures

Both application and end-use temperature requirements must be taken into account. Some products may still contain process heat, while others may be subjected to thermal processing or freezing. End-use temperatures may be environmental or may involve use conditions such as boil-in-bag, retort or microwavable applications.

## Humidity and Water Resistance

Water resistance is described in terms like good, poor, fair, waterproof and ice-proof. There are varying degrees of water resistance, ranging from merely resisting high humidity to being totally waterproof when immersed.

Poor water resistance generally means easier cleanup. Good water resistance is necessary when the item being packed is wet or the package will be exposed to weather or freezer conditions. Ice-proof adhesives (adhesives that remain adhered when immersed in cold water) are needed for brewery and soft drink labeling.

## Chemical Resistance

Adhesives can be softened or plasticized by oils or plasticizer compounds that migrate from other materials. Polyvinyl chloride plasticizers are especially notorious. Products also may contain volatile ingredients that will deteriorate bond

strength, such as oil of wintergreen, limonene and hazelnut oil. Special consideration and care are needed when silicone materials are used in the process or plant to prevent contamination and debonding issues. An adhesive's chemical resistance should be verified in applications involving solvents or other aggressive chemicals.

## Food Applications

All adhesives used in food applications must be tested and approved in laminated construction with barrier properties confirmed and approved for use. The food-use status for adhesives is regulated in the U.S. by the Food and Drug Administration (21 CFR 175.105) or in Canada by the Canadian Health Protection Branch. These government bodies dictate under what conditions of use and end-use applications a particular adhesive can be safely used. Some adhesives are capable of imparting off-flavors or odors to some foodstuffs. However, this can be mitigated with the use of the proper packaging structure and adhesive combination.

## Color

Dark-colored adhesives may show through substrates with poor opacity. In other applications, color may be added to provide visual evidence of spray or wheel patterns on white board. Hot melts that have been degraded are darker than the color stated on datasheets, indicating aging or degradation.

## Specific Density (Weight/Gal. or Kg/Liter)

Specific density is the ratio of product density to that of water at the same temperature. Most adhesives are sold by weight. If they were always used by weight, usage calculations would be simple, but most adhesives and coatings are used by volume (for example, 1 drum/100,000 cases); therefore, the lower-density product will provide better yield if all other characteristics are equal.

Some adhesives are extended with fillers and appear less costly when comparing price per kilogram, but when density (kilogram per liter (kg/L)) is taken into account, they are, in fact, more expensive. If density figures are not available, look at the invoice cost per drum. Compare drums that are the same *volume*. For example:

Product A — \$1.35/kg (density 1.1 kg/L)  
Product B — \$1.45/kg (density 1.01 kg/L)

Product A — cost/L  $\$1.35 \times 1.1 = \$1.48/L$   
Product B — cost/L  $\$1.45 \times 1.01 = \$1.47/L$

Product B costs more per kilogram but is the better buy by volume. This assumes that it will be used by volume (extrusion, smooth roll, wheel).

## pH (Water-Based Adhesives Only)

Adhesives at pH extremes, either acidic (1 to 6) or basic/alkaline (8 to 14), should run on stainless-steel equipment. Acidic and alkaline systems are generally not compatible and will coagulate when mixed. Resin emulsions usually are acidic. Most latexes and borated dextrins are alkaline. Some substrates can be affected by extreme pH values. Aluminum foil, for example, corrodes quickly in the presence of alkali.

## Solids or Nonvolatiles Content

Solids content refers to the solid material that is left behind to do the actual binding of the substrates once the solvent or water carrier is removed. Hot melts are 100% solids. Water- and solvent-based adhesives can be compared on a dry-weight basis when comparing relative cost.

Product A: 40% solids at \$1.25/kg wet, or  $\frac{\$1.25}{0.40} = \$3.125/\text{kg dry}$

Product B: 60% solids at \$1.25/kg wet, or  $\frac{\$1.25}{0.60} = \$2.083/\text{kg dry}$

If applying 5 grams of coating per square meter, Product B is the better buy, since its dry weight is about \$1.04 less per kilogram.

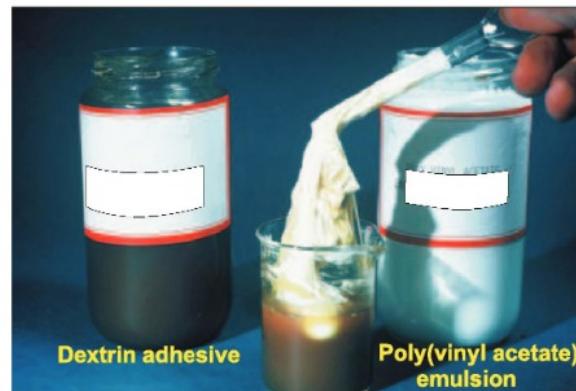
## Storage Life and Storage Conditions

Most liquid adhesives have a storage life during which they will give optimum performance. The oldest stock always should be used first. Adhesives become thicker in cold temperatures and thinner when it is hot. Adhesives generally are formulated to work at room temperature. Accordingly, some attention must be given to storing adhesives at reasonable temperatures. (15–32°C/60–90°F.) If necessary, move adhesives into the production area to condition them to the plant temperature. Some adhesives (e.g., emulsions) coagulate if frozen.

## Diluting Adhesives

Dilution of adhesives should be undertaken with care and guidance from the supplier to ensure performance remains as expected. Where it is necessary to add water to an adhesive reservoir to make up for evaporation losses, always use an adhesive liquor mixture of half adhesive and half water. Bear in mind that a thixotropic adhesive may appear to be semi-solid after standing for a while. Always stir an adhesive and measure viscosity before making any decision about adding diluents.

Adhesives should never be mixed without the express direction of the supplier, even though they may share the same resin or solvent base. For example, a borated dextrin adhesive and an emulsion-based adhesive are both water-dispersible. However, the dextrin is alkaline (pH 9) while the emulsion is acidic. Mixing the two up-

**Figure 14.13**

The result of mixing a water-based dextrin adhesive with a water-dispersed polyvinyl acetate emulsion.

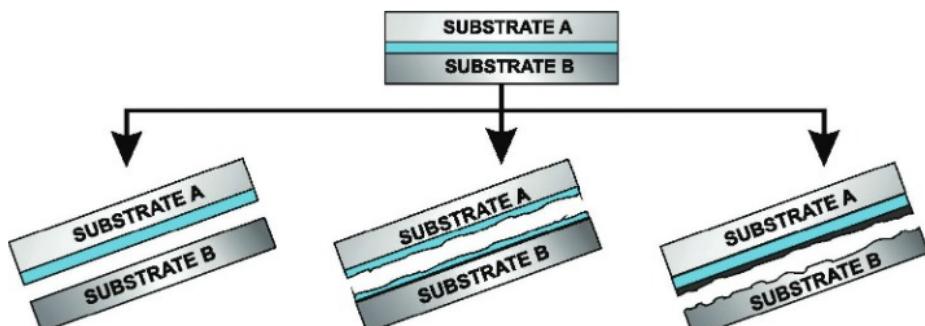
sets the pH balance and breaks the emulsion. The emulsion resin coagulates into a large, insoluble lump (See Figure 14.13) Similarly, the polymeric adhesive dissolved within a solvent-based adhesive may precipitate out of solution if diluted with an incompatible solvent.

## INSPECTING BOND FAILURES

Bond failure has many potential causes and is understood by closely inspecting the bond line on both substrates. Identifying what actually came apart is the first step in tracking down the cause of a failure. A close inspection of the failed surfaces is usually the first step and best done with a good magnifying glass. Figure 14.14 shows three possible outcomes of such an inspection:

- All the adhesive is attached to one of the substrates.
- Some adhesive is visible on both substrates.
- Separation has occurred in the substrate.

A fourth possibility is that adhesive has not covered the complete bonding area.

**Figure 14.14**

When analyzing a bonding failure, it is important to identify exactly where the separation took place—an adhesive failure, a cohesive failure or a substrate failure.

An adhesive failure indicates that the applied adhesive was unable to form a bond to the substrate. This narrows the search down to that interface. Questions to ask:

- Were the surfaces brought together past the adhesive's effective open time?
- Is the dyne level of the substrate without adhesive too low?
- Are surface interference layers such as processing oils, antistatic agents, slip additives, release agents or other materials present?

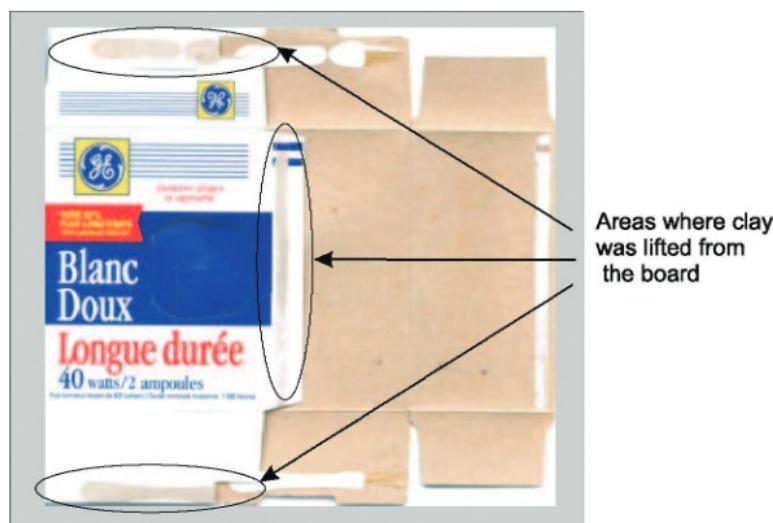
A cohesive failure suggests that the adhesive does not have enough cohesive strength for the application or that the adhesive application was too heavy. In analyzing this kind of failure, bear in mind that certain volatiles (such as flavoring ingredients) and material additives (such as plasticizers) can migrate into some adhesives and substantially reduce cohesiveness.

If the inspection reveals that there is substrate attached to the adhesive interface, then the adhesive has bonded well to that substrate's surface, but the surfacing material has not bonded well to the mass of the substrate. Common examples of this kind of failure are:

- Surface fibers of a paperboard have been torn away (fiber tear failure).
- Clay coating has lifted off the paper. (See Figure 14.15)
- Printing ink or a varnish coating has separated from the substrate.
- A laminate layer has separated from the body of the laminate.

Areas devoid of adhesive on either substrate surface suggest incomplete adhesive coverage. This kind of failure will be accompanied by one of the other symptoms. The adhesive should be reapplied at the proper rate and the bond re-evaluated to see if it meets performance requirements.

**Figure 14.15**  
A clay-lift failure.  
Dried polyvinyl acetate adhesives are translucent, not white. The adhesive has lifted the clay and even some ink off the paperboard. Note that inks and other surface coatings should not extend over gluing areas.



## REVIEW QUESTIONS

- 1.** Explain the two theories of adhesion.
- 2.** Of the four adhesive types—starch, dextrin, hot melt and PVA emulsion—which have the highest solids content and which have the lowest?
- 3.** Name three features that might make hot melts a favored choice.
- 4.** Name two places where you would not use a hot melt.
- 5.** What are the major applications of the following adhesive classes: starch adhesive, casein adhesive and cold-seal adhesives? Why are they chosen for these applications?
- 6.** A production engineer is not happy with the strength of an adhesive bond, so he or she increases the amount of adhesive. To the engineer's surprise, the bond is even weaker. What has happened?
- 7.** You are examining the bond failure between a plastic film and a carton board. What might you conclude if you observed:
  - a.** All the adhesive is on the carton board.
  - b.** The adhesive is evenly distributed between the carton board and the plastic film.
  - c.** The adhesive is all on the plastic film, and the failure surface has a powdery whitish appearance.
  - d.** The adhesive is all on the film, and the failure surface has a lot of paper fiber stuck to it.
- 8.** What is the difference between a cohesive failure and an adhesive failure?
- 9.** What are the four basic solidification methods for adhesives?
- 10.** What is meant by the term "wettability," what does it indicate and why is it important?
- 11.** List five factors to consider when selecting an adhesive for an application.
- 12.** A PVA emulsion adhesive will form an initial adhesive bond much faster than a dextrin adhesive with the same solids content. Why?
- 13.** True or false:
  - a.** Viscosity is a good indicator of solids content.
  - b.** Two different adhesives can be mixed, providing they are both water-based systems.
  - c.** A cold-seal adhesive tends to stick to itself.
- 14.** Describe the flow characteristics of a thixotropic fluid.
- 15.** Why is it important to know the viscosity of an adhesive at several shear rates?

- 16.** What does corona treatment do?
- 17.** What are the two main uses for pressure-sensitive adhesives?
- 18.** What are four types of flexible laminating adhesives?



# FLEXIBLE PACKAGING LAMINATES

15

## CONTENTS

### Laminates

Why make laminated packaging materials, desired properties.

### Aluminum Foil

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### Vacuum Metallizing

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### Flexible Bags, Pouches and Sachets

Vertical and horizontal form-fill-seal machines,

multi-lane form-fill-seal machines, basic pouch styles, advantages and disadvantages.

### Sealability

Heat-seal materials and applications, cold seals, typical seal temperatures.

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### Aesthetics and Other Properties

Clarity, reverse printing, metallizing, tie layers, primers, reflecting radiant heat, static dissipation.

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Coating stations, solventless laminating, coextraction.

### Specifying Laminates

Listing plies, caliper measurement conventions, standard roll orientation descriptions.

### Examples of Laminates

Typical laminate constructions with and without aluminum foil.



## LAMINATES

The purpose of a laminate is to combine the best of all properties—protection, aesthetics, machinability and cost—into a single packaging structure. Laminates are made for the simple reason that there is no “super-substrate” possessing all desired properties for all applications. For example, polyethylene (PE) is economical and a good water-vapor barrier, but it is a poor oxygen barrier and may elongate if used to contain a heavy product. Polyethylene terephthalate (PET) is a better barrier to oxygen, but it does not heat-seal well, is moisture-sensitive and more expensive.

Flexible packaging based on laminates has been a major growth area in recent decades. Despite questions concerning the environmental status of multi-material laminates, these materials will continue to be a healthy part of the packaging mix simply because they typically are designed to replace a more material- or energy-intensive option.

A multilayer construction can be made by bonding together two or more selected material plies. The plies may be assembled by joining roll-fed materials using coater-laminating machines, by coextrusion of multiple layers of plastic or by some combination of these processes. Companies engaged in the production of laminated structures generally are classed as “converters.” Most converters also print the flexible materials they produce.

Usually, these plies are in roll-fed form. The problem of creating an optimum flexible packaging material for an application is resolved by selecting materials that have the individual desired properties and combining them into a single laminated structure featuring the most desirable attributes of the individual plies.

Individual laminate materials can best be examined by the quality or property they contribute to the final product.

- Compatibility with the product.
- Structural properties such as physical strength, elongation, puncture resistance, abrasion resistance and dead fold.

- Performance properties such as machinability, sealability and environmental tolerance (i.e., freezing, boil-in-bag, microwaving).
- Barrier properties against water vapor, gas, odor and ultraviolet (UV) light.
- Aesthetic properties such as clarity, opacity, feel and metallic appearance.

These and other required performance characteristics must be delivered at minimum cost. Laminates are assembled from various combinations of paper, adhesives, plastic films, surface coatings, aluminum foils and aluminum metallized paper and plastic. With the exception of aluminum, all of these materials have been discussed in previous chapters.

## ALUMINUM FOIL

Aluminum is made from bauxite, a clay-like deposit containing aluminum oxides and silicates. Pure aluminum is a soft, silvery white, comparatively light metal (about one-third the weight of steel). It is ductile and malleable at normal temperatures and a good conductor of heat and electricity.

Aluminum alloys containing small amounts of copper, zinc, magnesium, manganese and/or chromium have excellent strength properties. Alloys 1100, 1145 and 1235 are most commonly used for reroll stock. Alloy 3003, containing manganese, is used in applications such as pie plates, where good draw and greater stiffness are required. Aluminum and its alloys can be reclaimed readily at about 5% of the energy consumption required to refine the original ore.

### Aluminum Foil Production

By definition, rolled aluminum in thicknesses less than 152.4 micrometers ( $\mu\text{m}$ ) (0.006 in.) is called foil. Foil is produced by being rolled from ingots or by continuous casting in-line with the furnace. All foil is supplied in 0 temper, the softest, most workable form.

A typical continuous-casting foil production line runs in-line from the melting furnace to a winding reel. The system continuously feeds, casts, chills and coils the foil, eliminating an intermediate ingot-making step. Continuous-cast foil stock does not need to be re-annealed when being converted to foil. It is in an annealed condition as fabricated. Ingot-rolled stock must be re-annealed between mill passes to eliminate work hardening and restore workability.

Rolling is a form of extrusion. Aluminum entering the roll nip encounters a squeezing force exerted downward and in the machine direction. The displaced metal is moved or extruded through the nip, and always in the web travel direction because this offers the least resistance to metal flow. Each pass through a rolling mill reduces metal thickness and at the same time increases its length, while the width remains essentially the same.

The work rolls that come into contact with the metal have finely ground, polished surfaces to ensure flatness and a bright finish. The work rolls are paired with

**Table 15.1**  
**Standard aluminum foil finishes and treatments used in packaging.**

Type of Finish	Description
Bright two sides (B2S)	uniform bright specular finish, two sides
Extra-bright two sides (EB2S)	uniform extra-bright specular finish, two sides
Matte one side (M1S)	diffuse reflecting finish, one side
Matte two sides (M2S)	diffuse reflecting finish, two sides
Embossed	pattern impressed by engraved roll or plate
Annealed	completely softened by thermal treatment
Chemically cleaned	chemically washed to remove lubricants
Hard	foil fully work-hardened by rolling
Intermediate temper	foil temper between annealed and hard

heavier backup rolls, which bear against the work rolls, exerting pressure to help prevent deflection of the work rolls. This ensures gauge uniformity across the web.

The foil faces in contact with the work rolls are polished to a bright finish. When a single web is run, both sides are bright. Foil gauges less than 25  $\mu\text{m}$  (0.001 in.) usually pass through the nip back-to-back, two at a time. The foil-to-foil face of each web has a satin-like matte finish. Other finishes can be produced with special patterns on work rolls or, more commonly, by using separate or in-line mechanical finishing machines. (See Table 15.1)

## Chemical Characteristics

When exposed to air, an aluminum surface naturally acquires a hard, transparent oxide layer that resists further oxidation. Resistance to chemical attack depends on the specific compound or agent which the foil contacts. Aluminum resists mildly acidic products better than mildly alkaline compounds such as soaps or detergents. Strong mineral acids will corrode bare foil. The mild organic acids generally found in food have little or no effect on aluminum.

Aluminum has high resistance to most fats, petroleum-based greases and organic solvents. Generally, food products such as candies, milk, unsalted meats, butter and margarine are compatible with bare aluminum, as are many drug and cosmetic products.

Intermittent contact with clean water has no visible effect on aluminum foil. However, in the presence of some salts and caustics, standing water can be corrosive. Hygroscopic products may cause corrosion if packaged in bare aluminum foil, particularly where a product contains salt or some mild organic acid. Applications that may subject aluminum to mild attack use coated or laminated stock on the

product-contact surface. The decision as to whether to use a bare, coated or laminated surface in contact with a product must be based on reliable information and suitable testing.

## Aluminum Foil in Flexible Packaging

Aluminum foil has many unique qualities that account for its widespread use in packaging.

<b>Appearance</b>	Aluminum foil has a bright, reflective metallic gloss that projects an exceptionally attractive, upscale appearance. In packaging, all reflective gloss surfaces are either solid aluminum foil or an aluminum metallized surface.
<b>Barrier Properties</b>	Heavier foil gauges ( $> 17 \mu\text{m}/0.0007 \text{ in.}$ ) are 100% barrier to all gases. As thickness is reduced, pinholing becomes more common. Typical water-vapor transmission rate (WVTR) for 0.00035-in. foil is 0.02 grams or less per 100 square inches per 24 hours (g/100 sq. in./24 hr). Many foil applications make use of foil's excellent gas and light barrier properties. Food and non-food products that are UV-light degradable are protected by foil's opacity.
<b>Dead fold</b>	Foil has superior dead-fold properties. Dead fold is the ability of a material to hold the geometry of a fold. Wraps that must stay in place without adhesive assistance and roll-up collapsible tubes require this property.
<b>Friability</b>	Unsupported foil is easily punctured and torn, key properties when designing unit-dose and dispensing-tablet packages as well as various tear-away seals. An added benefit is the inherent tamper evidence.
<b>Hygienic</b>	Aluminum foil sterilizes easily. The smooth, metallic surface does not absorb contaminants. It is inert to or forms no harmful compounds with most food, cosmetic or other chemical products.
<b>Conductivity</b>	Microwave susceptor films, electrostatic shielding and induction heat-sealing are examples of applications that depend on aluminum's ability to conduct electricity and heat.
<b>Formability</b>	Aluminum is a ductile metal. Heavier foils can be molded into trays and cups. Sheet stock is drawn into a variety of beverage and other can types. Solid aluminum slugs are impact-extruded into collapsible tubes, cigar humidor tubes and aerosol cans.

Foils are available in thicknesses of as little as 4  $\mu\text{m}$  (0.00017 in.). The selection of foil alloys, gauges and tempers for bare conversion or for combining with other materials will be determined by the end-use and by conversion process requirements.

## Foil Coatings

Packaging applications for plain foil are relatively limited and largely decorative. In most applications, aluminum foil is coated, and such coating may:

- Render the foil surface heat-sealable.
- Increase scratch or scuff resistance.
- Increase tensile or burst strength.
- Produce a specific surface (e.g., slip, nonslip, release, decorative).
- Improve adhesion of other coatings or printing inks.
- Enhance the water-vapor/gas-barrier properties of light-gauge foils.
- Increase resistance to corrosive agents or products.
- Impart high gloss and three-dimensional depth to foil decoration or printing.
- Lubricate during converting or processing operations.

Coatings are employed to protect the package, the product or both. Coatings generally can be classified as decorative, protective or heat-sealing. In most instances, a coating is selected for one characteristic, but one coating may embody all three, as in a tinted, heat-sealable coating with high food-product compatibility.

Transparent lacquers and varnishes allow the brilliant reflective metallic sheen to show through. A transparent yellow lacquer would give the appearance of gold, while a transparent reddish orange would look like a copper alloy. Foil printed with an opaque ink has a particularly smooth, hard appearance.

The inherent heat-sealability of many protective coatings is a bonus. Effective heat-seal coatings provide strong, usually airtight seams and closures. Polyvinyl chloride (PVC) heat-seal coatings are widely used with aluminum foil, but other formulations are available. It is essential that the coating be compatible with all materials it contacts to protect and seal the contents.

Heat-seal coatings do not appreciably add to a foil's bursting or tear strength in thicknesses less than 25  $\mu\text{m}$  (0.001 in.).

Various polymeric coatings are applied by extrusion or coextrusion. More typically, such coatings are used in combination with foil and other substrates such as papers, paperboards and plastic films to produce a multi-property laminated material. Potential coating applications should be developed as individual cases. Selected materials and application weights should satisfy production criteria for coating and converting. Table 15.2 lists the chemical resistance properties of common coating materials.

## Decorating and Printing

Foil offers graphic designers a unique surface capable of producing a kaleidoscope of attractive effects unattainable with other materials. Unlike paper, foil is fluid in its play of light and shadow and tends to pick up surrounding tones and light values. Thus, it can shine bright white, recede into rich black or reflect colors from adjacent

objects. While this mirror-like quality provides the essential excitement in foil design, it should be exploited or muted with intelligence and discretion.

Type on foil, unless fairly large, tends to be overpowered by the surrounding brilliance and may prove difficult to read. Reverse type on bare foil should be avoided unless it is display size. Opaque white often is laid down first to avoid reflectivity in a given design element and to provide a base for fine-screen process work. Foil can be used to design advantage within the printed design, shining through appropriate areas of the process halftones.

Foil that is to be printed usually is given a primer or wash coat to anchor the ink. A further function is to provide a barrier to keep undesirable materials from coming into contact with the foil surface before printing or coating. Wash coating frequently is done in conjunction with a laminating operation. Shellacs and vinyls are common primers for rotogravure and flexo printing. Heavier coatings, generally vinyl copolymer or nitrocellulose, are applied for lithographic printing. A second coating sometimes is applied over the printing to impart scuff resistance or to reduce surface friction.

Thin, annealed foil is readily embossed by passing the web between an engraved steel roll and a soft matrix roll. Laminated foils or heavier-gauge foils may be em-

**Table 15.2**  
**Chemical resistance of coating materials.**

Coating Type	Acid	Alkali	Water	Solvent
Acrylics	fair	fair	fair	good
Alkyd	fair	fair	good	good
Butadiene-styrene	excellent	excellent	excellent	good
Butyrate	fair	fair	fair	fair
Cellulose acetate	fair	fair	fair	fair
Chlorinated rubber	excellent	excellent	excellent	fair
Epoxies	excellent	excellent	excellent	excellent
Ethyl cellulose	fair	excellent	good	fair
Melamine	excellent	excellent	good	good
Nitrocellulose	good	fair	excellent	good
Polyamide-epoxy	fair	excellent	excellent	good
Polyester	good	fair	good	good
Polystyrene	excellent	excellent	excellent	fair
Polyvinyl acetate	fair	fair	good	poor
Polyvinylidene chloride	excellent	excellent	excellent	fair
PVA chloride copolymer	excellent	excellent	excellent	fair
Urea	excellent	excellent	excellent	good

*Source: Aluminum Association, Aluminum Standards and Data*

bossed with two engraved steel rolls. The design positive is engraved on one roll, the design negative is engraved on the other. Embossed copy can be used in applications where plain or coated foil is allowed, but printing inks or lacquer cannot be used.

The multiple “pre-creasing” effects achieved with an overall embossed pattern generally improve dead-fold properties. This is an advantage in packaging where non-adhered overlaps and end folds are employed (e.g., butter and margarine wraps).

## Foil Pinholing and Flex Cracking

Most foils used for packaging applications are in gauges less than 13  $\mu\text{m}$  (0.0005 in.). Household foil is about 18  $\mu\text{m}$  (0.0007 in.). Although solid aluminum foils theoretically offer a total barrier to all gases, minute holes occur at thinner gauges because of metallurgical impurities and variations. “Pinholing” increases as foil gauge decreases and is a major pathway for gas penetration. Gas penetration through pinholes is reduced somewhat when a foil is coated or laminated with polymeric materials.

Aluminum foils also are subject to “flex cracking,” the splitting of the foil when worked. A flex crack can provide a significant entry point for gases. Heavy laminates tend to reduce the tendency to flex crack.

Foil laminates intended for barrier applications should be evaluated for barrier properties on the finished package after all machining is complete and preferably after a real or simulated shipping cycle. It is not uncommon for a prospective barrier laminate to have no measurable permeability in the flat but to have significant permeability when formed, folded and creased into a package.

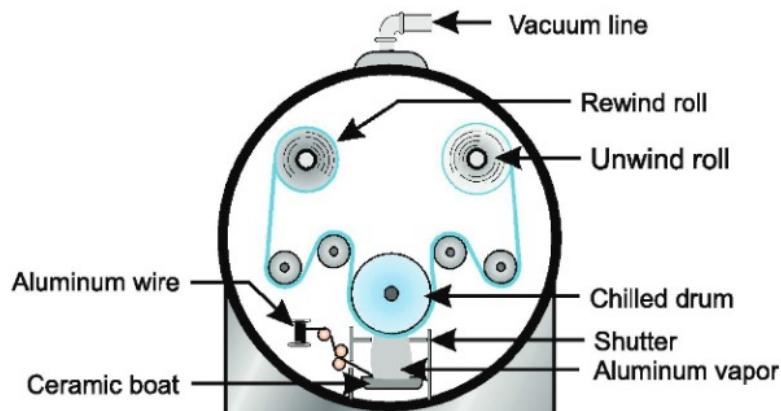
## VACUUM METALLIZING

### The Metallizing Process

“Vacuum metallizing” refers to the depositing of a metal layer onto a substrate, carried out in a vacuum. Although many metals can be vacuum-deposited, only aluminum is used in packaging. The process, developed in the late 1940s, emerged as an important option for flexible packaging in the 1970s. Currently, packaging is the largest consumer of metallized papers and plastic films.

The initial role of metallized materials was for decorative and aesthetic values. Recognition of the materials’ functional properties has greatly extended packaging applications. Metallizing plastics improves gas- and light-barrier properties, provides heat and light reflectance and electrical conductivity. The barrier properties achieved are a product of the thickness of the metal deposit and the properties of the substrate being metallized.

Most metallizing is done as a batch process. A typical system employs a horizontal tubular chamber, up to 2.1 meters (m) (84 in.) in diameter and 2.8-m (110-in.) long. Paper or film rolls are loaded onto unwind stations on one side of the chamber. The web is led down through tension rolls, under a large chilled roller, and through tension rollers to a rewind roll. (See Figure 15.1) A vacuum is needed

**Figure 15.1**

Cross-section of a representative batch metallizing chamber.

within the chamber to help aluminum vaporize at a lower temperature and to minimize oxidation of the metal vapor as it rises to the web.

Pure aluminum wire, approximately 3.2 millimeters (mm) (1/8 in.) thick, is fed into machined metal “boats” located below the chilled drum. These are electrically heated to aluminum vaporizing temperatures. The boats rest in water-cooled troughs to extract radiant heat and minimize stray vaporization. Vaporized aluminum rises and then condenses on the underside of the film or paper web as it passes over the chill roll. The thickness of the metal deposited is controlled by a combination of web speed, wire feed rate and boat temperature.

Pattern metallizing is not possible with current technology; however, metallized pattern effects can be achieved by metallizing a preprinted film. Another process uses caustic solutions to selectively remove the metallized layer to create clear windows in a metallized film.

## Vacuum Metallizing Paper

Most metallized papers are quality virgin stocks clay-coated on one or two sides, depending on end-use criteria. The weight of the clay coating varies, but, generally, higher coating weights provide a smoother surface and higher reflective values in the metallized surface. All paper stock must be lacquer coated before being metallized. The gravure-applied lacquer seals the surface, enhances surface smoothness and promotes consistent metal adhesion.

Since the high vacuum within the chamber will boil away moisture, the paper's moisture content is normally reduced to less than 5%. Remoisturizing is an essential production step after metallizing paper to reestablish correct moisture content in the paper and improve its resistance to curling. Gravure coaters apply the primer coating for post-metallizing printing.

Vacuum-metallized paper gains the aesthetic appeal of a reflective aluminum surface and improved barrier properties. Labelstock is a major market for metallized papers.

## Vacuum Metallizing Films

Plastic film being metallized does not need to be sealed, smoothed or dried as a paper substrate does. In addition to adding decorative appeal, metallizing a plastic film significantly improves barrier properties to all gases. Although most plastic films can be metallized, oriented polypropylene (OPP), PET and nylon (PA) are the most commonly metallized films.

OPP is the most widely metallized film. Snack-food packaging is its single largest application, with potato chip bags being a major consumer. Metallization complements OPP's properties. OPP film:

- Has excellent moisture barrier.
- Offers use temperatures up to 150°C (300°F)
- Is a limited oxygen barrier (significantly improved by metallizing).
- Is economical.
- Produces a fair metal-to-film bond.

Desirable properties also encourage PET's use. This material:

- Produces the best metal-to-film bond.
- Offers the best combination of oxygen-, moisture- and UV light-barrier properties.
- Offers high use temperatures (up to 205°C/400°F)

Metallized biaxially oriented nylon (BON) films first gained market share in retail and institutional flexible packaging of ground coffee because of nylon's barrier qualities and resistance to abrasive coffee granules. Metallized PET also is used in this market niche because of current cost advantages. BON film:

- Is a good oxygen barrier.
- Has excellent tear, abrasion, flex crack and puncture resistance.
- Is hygroscopic (modest moisture barrier).
- Is more costly than OPP or PET.

Metallized films are used alone in some applications but are usually a component in a laminated structure.

## Microwave Applications

Metallizing is used in "susceptor" packaging where the metallized component serves to create a local microwave energy "hot spot" (the aluminum converts microwave energy to radiant heat). Microwave popcorn and frozen pizza are two applications where metallized susceptors are used. Since susceptors are exposed to high temperatures, PET is the base material of choice. The metal deposition level is low.

**Table 15.3**  
**Conversion table for aluminum deposition.**  
**Typical applications call for about 2% light transmission.**

Angstroms	Optical Density	Percent Transmission	Ohms/sq. Resistance
50.8	1.10	7.94	5.35
63.5	1.20	6.31	4.55
71.1	1.30	5.01	3.98
81.3	1.40	3.98	3.50
84.0	1.50	3.16	3.32
98.5	1.60	2.51	3.06
101.6	1.70	2.00	2.86
106.7	1.80	1.59	2.68
114.3	1.90	1.26	2.50
121.9	2.00	1.00	2.35
127.0	2.10	0.79	2.20

## Measuring Metal Deposition

Metal deposition thickness is one factor determining a metallized substrate's barrier properties. The aluminum deposition is on the order of 1 millionth of an inch, and so thickness measurement must be done indirectly.

Electrical resistance and optical density are two methods used to measure the deposited layer's thickness. The industry prefers the optical density method when measuring deposition on clear plastic films. A densitometer measures the amount of light that penetrates through a metallized material, providing data that is expressed as a percentage of light transmission. Electrical resistance is expressed in terms of ohms per square. The expressions are readily converted. (See Table 15.3)

## OTHER NON-ORGANIC COATINGS AND BARRIER TREATMENTS

An advantage of aluminum vacuum metallizing of plastic films is the significant increase in barrier properties. However, by its nature, the aluminum deposit makes the package opaque. This is a benefit in some applications since it eliminates UV-light degradation. However, in many instances, high gas barrier and high clarity are desirable as well.

Work is ongoing to develop other inorganic treatments to improve barrier and retain clarity at the same time. Significant advances have been made in depositing silicon oxides ( $\text{SiO}_x$ ) and carbon (DLC or diamond-like coating). Both methods use plasma deposition technology rather than vacuum metallizing.

**Silicone oxide.** Like aluminum,  $\text{SiO}_x$  (or glass) coatings significantly improve gas barrier. Oxygen permeation values of  $0.046 \text{ cc/m}^2/24 \text{ hr}$  ( $0.003 \text{ cc/100 sq. in.}/24 \text{ hr}$ ) have been reported. A significant advantage is that these coated films are clear and, unlike aluminum metallized films, glass-coated films can be microwaved. The glass coating is clear and tolerates folding and flexing of the film without significant loss of barrier.

The coating is applied using plasma technology. Plasma is a gas that has been activated using electromagnetic energy sources to the point at which portions of the gas separate into electrons, free radicals, ions and other excited-state species. Fluorescent and neon lights are examples of this process.

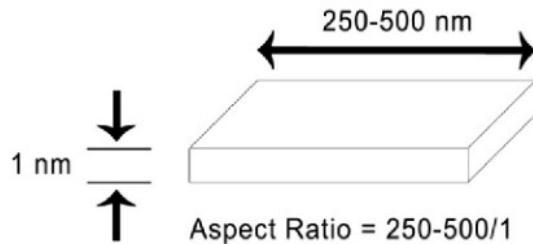
The highly reactive species present in plasma interact with the first few atomic layers of a surface, breaking some chemical bonds and forming others. These reactions change material surface properties without changing bulk properties. The deposition of thin films of silicon oxides (on the order of 500 angstroms) onto PET, PP, polyamide (PA) or other film surfaces is of interest to the packaging industry.

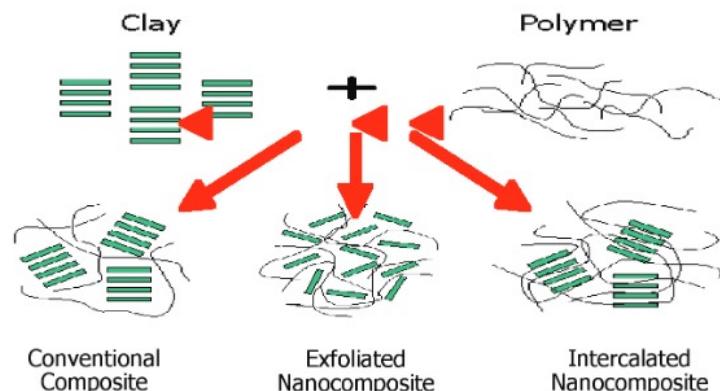
The cost of producing  $\text{SiO}_x$ -coated films is still high, but some commercial applications, notably in the medical supply sector, use the technology.

**Carbon coatings.** Several companies have developed methods for depositing thin films of carbon over plastic substrates. The coatings are clear and claim to offer substantial barrier improvement over untreated plastic.

**Nanocomposite.** Nanocomposites incorporate extremely fine particles of plate-like minerals such as clay into the plastic. The nanosized particles have a high aspect ratio. (See Figure 15.2) The mineral platelets themselves are not permeable to gases; so, a permeating molecule has to go around each platelet. The overall effect is that a permeating molecule has to work its way through a circuitous path that is several orders of magnitude greater than the actual thickness of the film. Exfoliation and intercalation increase the complexity of the tortuous path and enhance nanocomposite properties. (See Figure 15.3) Nanocomposite films are said to be relatively clear.

**Figure 15.2**  
High aspect ratio materials used for nanocomposites.





**Figure 15.3**  
A high degree of exfoliation/intercalation is desired for enhanced properties.

## LAMINATE STRUCTURAL AND PHYSICAL PROPERTIES

Structural properties are related to physical strength and performance. Physical strength is needed to hold the product. Relatively little strength is required to hold packaged dry soup, coffee or confectionery products; more is needed when designing a 20-kilogram bag for industrial or bulk products.

For large bags, one might suppose that a material with high tensile strength such as PET would be a good choice. However, material in a large bulk bag must be resistant to tear propagation. It should be reasonably flexible in the heavy gauges that would be used, and the large bag size puts a premium on material economy. Medium-density polyethylene, low-density polyethylene (LDPE) and linear low-density polyethylene (LLDPE) better meet these requirements. The bags may be monolayer or could be coextruded with LLDPE, Surlyn or ethylene-vinyl acetate (EVA) as a heat-sealing layer. Additional layers might be incorporated if high barrier is required.

A material with low elongation is desirable for heavy products; otherwise, the weight would distort or stretch the package. Materials such as PET provide high tensile strength and low elongation. However, even though PE has high elongation compared with polyester, the thick film gauges used for heavy products usually minimize this problem. Heavy-gauge PE combinations provide the performance needed at a lower cost.

The property of “toughness”—the ability to resist puncture and abrasion—is needed for products that are abrasive or that have sharp edges. Nylon provides this, and frozen primal meat cuts are packed in nylon-based laminates for this reason. Some coffee brick pack laminates have a nylon layer to resist the abrasiveness of coffee grounds.

Product weight or physical characteristics are not the only structural criteria. Retort pouches, for example, must undergo commercial sterilization that subjects the pouch to extreme temperatures and pressure. End-use and consumer preference also may dictate structural elements. Both a paperboard box and a PE bag will hold fluid, but the paperboard box stands by itself. Stiffer materials must be used where pouches must stand by themselves. A gusseted bottom provides the required geometry to stiffen a flexible pouch.

## Coefficient of Friction

Machinability is a composite of many properties, one of the most important being coefficient of friction (CoF). CoF refers to the material's ability to slide over itself, the product or a machine part during conveying, filling, collating and casing operations. It may be improved by adding amide-based slip agents.

CoF can be reported as static CoF (the force needed to start an object moving from a standstill) and kinetic, or dynamic, CoF (the force required to maintain motion once it has been initiated). Static and kinetic CoF are almost identical for some materials, while for others, static CoF can be significantly higher than kinetic CoF. Kinetic CoF is never higher than static CoF.

CoF can vary dramatically, depending on the surfaces being compared and the speed and temperatures at which the material is running. There are numerous CoF test procedures; always ensure that identical methods are being compared, and the appropriate test is being used. CoF is critical for vertical form-fill-seal (VFFS) equipment and somewhat less critical on horizontal form-fill-seal (HFFS) equipment.

Generally, a low CoF allows for easy running of the web over stationary parts. However, low CoF can detrimentally affect material feeds where a traction device is used to pull film through the operation. For example, in a VFFS machine, low CoF can make for a slippery, unstable package. A COF below 0.10 is too slippery for some applications.

ASTM D1894 Coefficient of Static and Kinetic Friction of Plastic Film and Sheet describes one method of determining friction values.

## Body and Dead-Fold Properties

Stiffness and "bulk" usually are obtained by incorporating economical paper layers into the laminate. Heavier aluminum foils, thicker-gauge plastics and cellular plastics also are used to impart stiffness, depending on other properties that may be desired.

Laminated collapsible tubes must have some "body" or substance as well as the ability to dead fold, so they can be rolled up as the contents are ejected. Both paper and foil are used in the laminate layers of this construction.

Some laminate constructions are used as simple wraps where the material's ability to conform to the wrapped object, and to stay permanently in position without a sealing medium, is vital. Aluminum foils have the best dead-fold properties, followed by paper. Most plastic films have relatively poor dead fold. However, some PP, high-density PE and PVC films have been designed to have reasonably good dead fold.

## Tear Properties

Films such as PET and PP tend to propagate tears; that is, once a small cut or puncture has been made in the film, a tear readily propagates from this point. Other films, such as the PEs, do not propagate a tear. It should be noted, that there can be marked differences in machine direction and cross direction tear propagation depending on the material and film manufacturing process.

While a package should not tear open in transit, easy opening is a user benefit. Most plastic laminates have awkward tear properties. Paper or aluminum foil layers can enhance tear properties. In instances where a notch-sensitive material is being used, a small nick at the laminate's edge can help initiate the tearing action.

## **Thermoformability**

Meat or cheese packs that have one part of the web drawn to a product-conforming tray require easy formability of the rollstock. The rollstock also needs to have clarity to show off the product, and it must have good oxygen-barrier properties. This combination of properties is best found in nylon-based laminates. The laminate would be coated with a barrier resin and an ionomer (Surlyn) heat-seal coating to seal through any fats on the seal line.

Laminated materials also are used to thermoform rigid high-barrier cups and tubs for shelf-stable microwavable products. The material for these applications is on the order of 380  $\mu\text{m}$  (0.015 in.) thick, compared to the 10–50  $\mu\text{m}$  (0.0004–0.002 in.) typical of flexible constructions.

## **Use Environments**

Laminate materials must be selected based on the environment the package will experience. Adhesives and components with low melting points can't be used for boil-in-bag, ovenable or microwaveable applications. The package would come apart. Unoriented PPs and some vinyls become brittle at low temperatures. PET and polycarbonate have the highest use temperature. For this reason, most dual-ovenable applications use PET as the base plies.

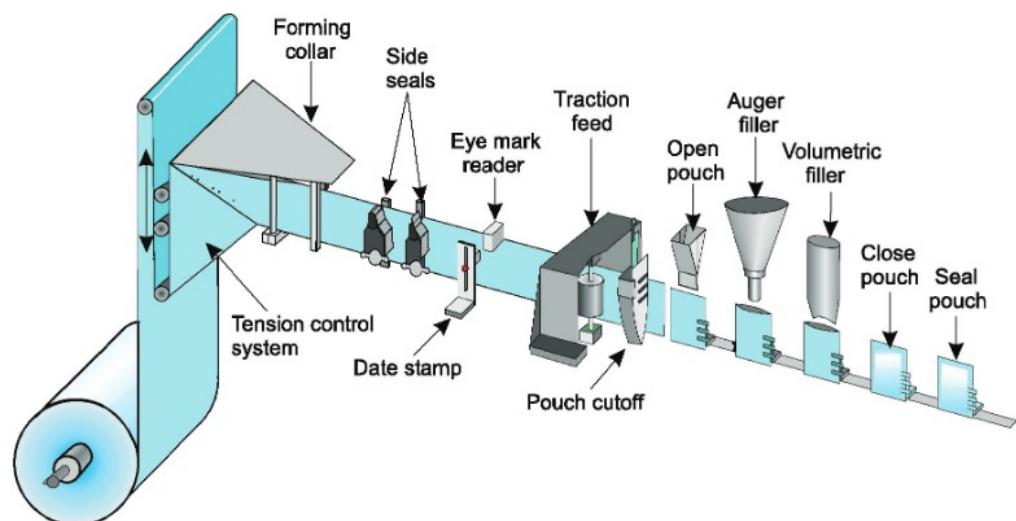
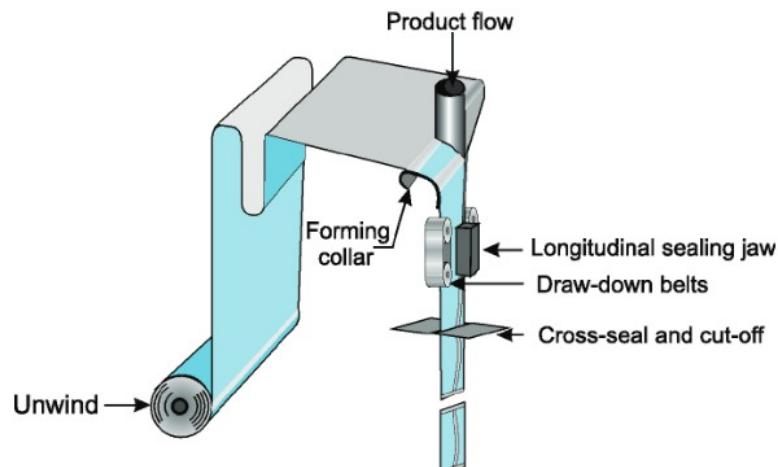
# **FLEXIBLE BAGS, POUCHES AND SACHETS**

## **Vertical and Horizontal Form-Fill-Seal Machines**

Every machine has its own characteristics and material requirements for optimum operation. Since most webs are pulled through a machine, the material's yield point, the force at which permanent deformation takes place, is critical. Where eye mark or other register points must be observed, recoverable elongation is also important. Other performance requirements will vary, depending on the laminate purpose and application.

A significant proportion of flexible packaging is produced and filled on VFFS or HFFS machines. (See Figure 15.4 and Figure 15.5) In a typical VFFS machine, the packaging material is unwound at the back of the machine and follows a vertical path over a forming collar where the flat material is shaped into a tube. A longitudinal seal is put into the tube, and the product is introduced from the top. After product filling, horizontal sealing bars place a heat-seal across the bag width, at the same time cutting across the center of the horizontal seal to separate one package, while leaving the tube sealed at the bottom ready to receive the next product dump.

**Figure 15.4**  
Material and product flow in a vertical form-fill-seal machine.



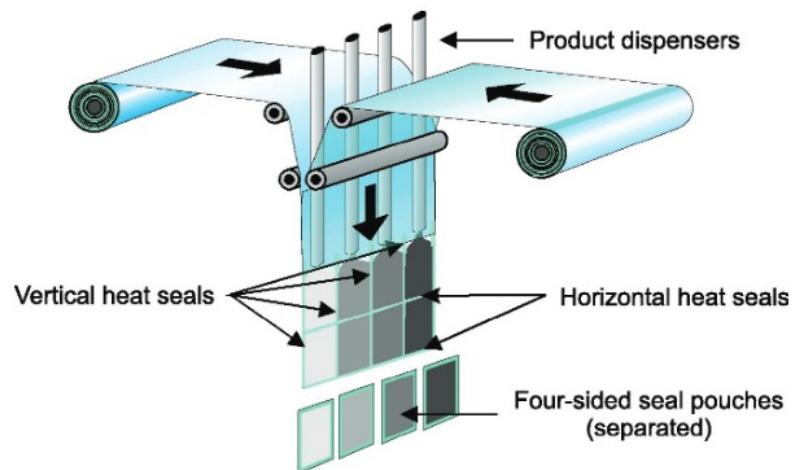
**Figure 15.5**  
Material and product flow in a horizontal form-fill-seal machine.

HFFS machines operate with the package rollstock being fed horizontally over a forming collar. Heat-seal bars seal the appropriate-sized pouch and, after filling, seal the completed package. Depending on machine design, the formed pouch may be cut away from the parent web before or after filling. In some designs, laminate material may be formed directly around the product.

Both machine types can be used to fill liquid, powder or granular materials or small multiple products. VFFS equipment typically occupies a smaller footprint but is more restricted in the number of filling or functional stations that can be grouped over the pouch. Horizontal machines can have a great number of operating stations arrayed along the horizontal travel path of the pouch. This allows for multiple filling heads, steam purges and other activities.

Multiple-lane VFFS machines mostly fill smaller pouches such as single-service condiments (mustard, ketchup, etc.) and sample sachets. (See Figure 15.6) Some high-volume larger pouches also are filled on multiple-lane machines. Since the machine is fed from two separate rolls, there is the opportunity to use two different materials, an opaque back and a clear front, for example.

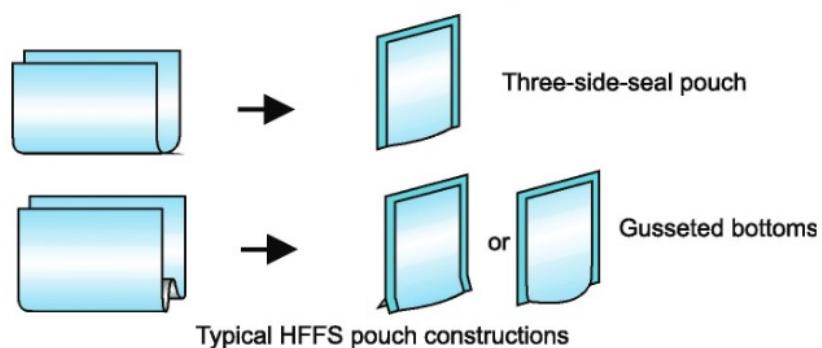
Pouches made on a VFFS machine are characterized by a seal across the pouch top and bottom and a vertical seal across the center of the back. A fin-style vertical seal is easier to make since it brings together two inside heat-seal-coated surfaces. However, it uses slightly more material, and the flattened seal is arguably not as aesthetically pleasing as a lap seal. A lap seal looks better and uses less material; however, it requires that an inside surface be able to bond to the package outside surface. (See Figure 15.7)



**Figure 15.6**  
A multiple-lane vertical form-fill-seal machine.



**Figure 15.7**  
Vertical and horizontal form-fill-seal machines produce pouches with different seal geometries.



Pouches made on HFFS machines are characterized by a three-sided edge seal. A graphics advantage is that both front and back panels are free of seals. HFFS pouches can be easily accommodated to produce gusseted stand-up pouches.

Multiple-lane FFS pouches will have four sealed edges.

## SEALABILITY

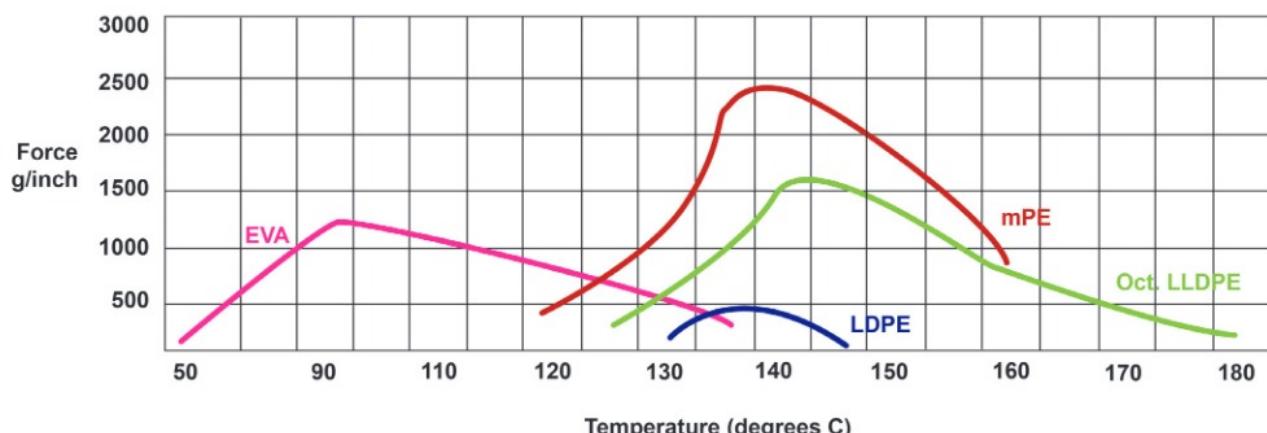
The majority of flexible packages are closed by heat-sealing. The layer that provides this capability is important, since seal integrity is absolutely essential, particularly for pharmaceuticals, foods, liquids and fine powders. Heat-seal materials must be closely matched to the machine and the operating parameters being used to create the seal.

Heat-sealing temperature, dwell time and sealing jaw pressure are the machine variables. However, a machine is set to run at a designed speed, so dwell time is a given within narrow limits. Jaw pressure also is fixed within narrow limits by the machine and difficult to measure. In practice, most heat-seal control involves manipulating the temperature.

Waxes and wax blends are the most economical heat-seal materials, but are not strong and have limited low- and high-temperature tolerance. They can be used only in noncritical applications.

LDPEs are the most common heat-sealing agents, although performance properties and cost vary widely, depending on the specific type of PE. These may be formulated with other additives or copolymers to improve selected adhesive qualities. PEs can be applied by extrusion, or a previously formed film can be bonded onto the laminate with an adhesive. In both instances, the film forms a layer over the entire laminate and contributes other properties as well as heat-sealability.

Where the seal requirements are more challenging, LDPE is replaced by more aggressive heat-seal options. Figure 15.8 shows hot-tack strength of different PE grades, and Table 15.4 indicates the general performance and cost of common heat-sealing materials.



**Figure 15.8**

A comparison of the hot-tack strength of ethylene-vinyl acetate, low-density polyethylene, octene linear low-density polyethylene and metallocene polyethylene. (Sources: DuPont; Nolan McDougal, Dow.)