CHAPTER 3: METAL PACKAGING

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3.1 Learning Objectives

This module has been written to provide a basic understanding of, and introduction to, metal packaging materials. On completion of this module, the student will have a general appreciation of the raw materials and processes used to manufacture metal packaging materials, as well as the major categories of metal packaging materials and their use in the packaging of food.

3.2 Introduction

Four metals are commonly used for the packaging of foods: steel, aluminum, tin and chromium. Tin and steel, and chromium and steel, are used as composite materials in the form of tinplate and electrolytically chromium-coated steel (ECCS), the latter being somewhat unhelpfully referred to as tin-free steel (TFS). Aluminum is used in the form of purified alloys containing small and carefully controlled amounts of magnesium and manganese. Two other metals are used during the soldering or welding of three-piece tinplate and ECCS containers: lead and copper. However, since they are not used for the fabrication of containers in their own right, they will not be discussed further in this chapter.

Today, tinplate and aluminum have become widely adopted for the manufacture of containers and closures for foods and beverages, due largely to several important qualities of these metals. These include their mechanical strength and resistance to working, low toxicity, superior barrier properties to gases, moisture and light, ability to withstand wide extremes of temperature and ideal surfaces for decoration and lacquering.

3.3 Tinplate

The term tinplate refers to low carbon mild steel sheet varying in thickness from around 0.15-0.5 mm with a coating of tin between 2.8-17 gsm (grams per square meter) (0.4-2.5 µm thick) on each surface of the material. The combination of tin and steel produces a material which has good strength combined with excellent fabrication qualities such as ductility (the capability to undergo extensive deformation without fracture) and drawability (these attributes arise from the grade of steel selected and the processing conditions employed in its manufacture) as well as good solderability, weldability, non-toxicity, lubricity, lacquerability and a corrosion resistant surface of bright appearance (these latter properties being due to the unique properties of tin). Furthermore, the tin coating adheres sufficiently well to the steel base that it will withstand any degree of deformation that the steel is able to withstand without flaking.

3.3.1 Manufacture of Pig Iron

The chemical composition of the base steel has a very significant effect on the subsequent corrosion resistance and mechanical properties of the tinplate. The iron ores used are generally hematite (Fe₂O₃) with some magnetite (Fe₃O₄). Commercial extraction of iron from its ores is carried out in blast furnaces, where a mixture of iron ores, solid fuel (coke) and fluxes (limestone and dolomite)
are heated to around 1800°C. This results in the reduction of most of the iron oxides to metallic iron (m.p. \(\approx 1200°C\)). Today modern blast furnaces are capable of producing molten iron of near constant composition at high rates.

### 3.3.2 Steelmaking

The pig iron from a blast furnace contains 3.5-5.0% carbon, 0.3-1.0% silicon, and up to 2.5% manganese, 1% phosphorous and 0.08% sulfur depending on the ore. These metalloids must be substantially reduced in the steelmaking stage, and this is commonly accomplished using a basic oxygen furnace. From the furnace the steel is cast into ingots which are subsequently rolled into slabs about 250 mm thick or, more commonly today, continuously cast into slab form.

![Blast furnace in steel mill](image)

The thick slabs are hot rolled down to about 2 mm, and during this process substantial layers (0.01 mm thick) of oxides or scale are formed as a consequence of the steel being heated to elevated temperatures for rolling. Next the scale is removed by a process called ‘pickling’ which uses a dilute aqueous solution of acid (typically 10-15% sulfuric acid) near its boiling point. After pickling the strip is recoiled and coated with an oil to prevent rust formation and act as a lubricant in subsequent operations.

The final stage of thickness reduction (typically 90% from about 2 mm to 0.2 mm) is carried out by cold rolling. The effects of cold rolling are to increase the strength and hardness of the steel, but this is done at the expense of ductility.

In the next stage (that of annealing), the steel is heated to temperatures of 600-700°C, causing recrystallisation of the elongated ferrite grains into new fine grains. This results in a marked increase in ductility and a corresponding decrease in strength.

To reduce the possibility of severe fluting, paneling or creasing, and to impart the desired surface finish, the steel is given a final, very light cold rolling (generally a reduction of 0.5-2.0% in thickness) in a ‘Temper’ mill. This imparts ‘springiness’ to the steel but changes the temper or surface hardness only slightly.

At this stage the uncoated steel sheet is referred to as black plate, so called because some of the early production was covered with black iron oxide. It is the raw material for electrolytic tinplate (ETP) and electrolytically chromium-coated steel (ECCS).

### 3.3.3 Tinplating

The traditional method for tinplating involved dipping or passing the steel through a bath of molten pure tin but since the 1930s the process of depositing tin by electroplating has been used. The introduction of the electroplating process enabled a
different thickness of tin to be applied to the two surfaces of the steel. This ‘differential tinplate’ is of economic benefit to the user since it enables the most cost-effective coating to be selected to withstand the different conditions of the interior and exterior of the container.

Plating is preceded by cleaning in a pickling and degreasing unit, followed by thorough washing to prepare the surface. After the plating stage, the coating is flow melted, passivated and finally lightly oiled.

Flow melting consists of heating the strip to a temperature above the melting point of tin (typically 260-270°C), followed by rapid quenching in water. During this treatment a small quantity of the tin-iron compound FeSn₂ is formed. The structure and weight of this alloy layer plays an important role in several forms of corrosion behavior.

A steel strip is then given a passivation treatment to render its surface more stable and resistant to the atmosphere. This generally involves an electrolytic treatment in a sodium dichromate electrolyte that results in the formation of a film (usually <1 μm thick) consisting basically of chromium and chromium oxides and tin oxides.

After passivation the plate is given a light oiling to help preserve it from attack and to assist the passage of sheets through container-forming machines without damaging the soft tin layer. Finally the strips are sheared into sheets or coiled, and then packed for shipment to the can manufacturers.

The final structure of the completed coating is shown below and consists of a tin/iron alloy layer (principally FeSn₂) adjacent to the steel base, free tin, a film of mixed oxides formed by the passivation process, and an oil film.

Schematic structure (not to scale) of tinplate showing main layers

The majority of tin mill products are used by the container industry in the manufacturing of cans, ends and closures for the food and beverage industry. Over 120 tinplate lines and 30 ECCS lines are operating in the world today.

Tinplate sheets are described in terms of a base box, a hangover from earlier times when tinplate was sold in units of 112 sheets, each 356 by 508 mm (14 by 20 inches). Such a package was known as a base box, and the area it contained (20.2325 m² or 31,360 in²) survives today as the unit area for the selling of tinplate. To convert to decimal thickness multiply the weight per base box by .00011. In the original system, 1 lb base box meant that 1 lb of tin was applied evenly to both sides of the plate, i.e. each side received 0.5 lb (equivalent to 11.2 gsm) of tinplate. This was given the designation in the
US of No. 100. Tinplate is now commonly graded using the metric unit SITA (Système International Tinplate Area) which is based on 100 m².

Tinplate sheets ready for dispatch.

3.4 Chromium-Coated Steel (ECCS)

The production of electrolytically chromium/chromium oxide coated low carbon steel sheet (to give ECCS its full name) is very similar to electrotinning, the only essential differences being that in the former case flow melting and chemical passivation are not involved. The initial development work was carried out in Japan in the 1960s when tin was on occasions in short supply, and the price extremely variable.

The process involves deposition in a dilute chromium plating electrolyte at a temperature in the range 50-70°C. As shown below, ECCS consists of a duplex coating of metallic chromium and chromium oxide. The ideal total coating weight is approximately 0.15 gsm which is much thinner than the lowest grade of electrolytic tinplate which has a tin thickness of 5.6 gsm.

The ECCS surface is more acceptable for protective enamel (lacquer) coatings or printing inks and varnishes than tinplate, and the lack of a low melting point (232°C) tin layer means that higher stoving temperatures and consequently shorter stoving times can be used for the enameling of ECCS. Unlike flow brightened tinplate, ECCS is a dull bluish color which necessitates modification of decoration processes to allow for its poor reflection.

However, ECCS is less resistant to corrosion than tinplate as it has no sacrificial tin layer, and therefore must be enameled on both sides. In addition, ECCS containers cannot be soldered with traditional lead or tin solders and therefore bonding of ECCS components must be by welding or the use of organic adhesives. If welded, ECCS must be edge cleaned prior to welding to remove the chromium layer. This is a slow, costly and mechanically inefficient process. ECCS ends are commonly used with tinplate bodies.
3.5 Aluminum

Aluminum is the earth's most abundant metallic constituent, comprising 8.8% of the earth's crust, with only the nonmetals O₂ and silicon being more abundant. Alumina or aluminum oxide (Al₂O₃) is the only oxide formed by aluminum and is found in nature most commonly as bauxite. The Hall-Héroult process is still the only method used for the commercial production of aluminum. Due to the chemical stability of its oxides, the energy requirements for smelting are extremely high. This has lead to the production of aluminum in areas where cheap electrical power is available.

Most commercial uses of aluminum require special properties that the pure metal cannot provide. Therefore, alloying agents are added to impart strength, improve formability characteristics and influence corrosion characteristics. A wide range of aluminum alloys is available commercially for packaging applications, depending on the container design and fabrication method being used. Commercially pure aluminum is used for the manufacture of foil and extruded containers since it is the least susceptible to work hardening. An alloy containing 4-5% Mg and 0.35% Mn produces a very rigid material suitable for manufacturing beverage can ends.

Compared with tinplate and ECCS, aluminum is a lighter, weaker but more ductile material that cannot be soldered.

3.6 Container-Making Processes

3.6.1 End Manufacture

The can end or lid is of complex design developed for optimum deformation behavior since it is important that the ends are able to deform under internal and external pressure without becoming permanently distorted. In effect they must act like diaphragms, expanding during thermal processing and returning to a concave profile when vacuum develops inside the can on cooling. The cross-section of a typical end design is shown below:

The ends are stamped on power presses from tinplate sheet which has been previously enameled. After stamping, the ends fall through the press into the curler to form the outside curl and diameter.

A lining or sealing compound is then applied into the seaming panel; the sealant used is based on natural or synthetic rubber and is dispersed in water or solvent. Its constituents are subject to stringent food regulations. The purpose of the sealant is to assist the formation of an hermetic (air-tight) seal by providing a gasket between adjacent layers of metal.

Several types of easy-opening devices such as the key opening scored strip found in solid meat or shallow fish
cans have been available for many years. However, an increased demand for convenience features has seen the development of easy-open ends of two broad types: those which provide a pouring aperture for dispensing liquid products, and those which give a near full aperture opening for removing more solid products.

Most designs incorporate an easy-open end consisting of a scored portion in the end panel and a levering tab (formed separately) which is riveted onto a bubble-like structure fabricated during pressing. Most but not all of the entire aperture circumference is scored, leaving sufficient unscored portion to function as a hinge when the tab is pressed in. Close control of scoring conditions is vital to ensure adequate resistance to bursting without requiring an unduly high tearing load to open. Recently a resealable end for carbonated beverage cans has been commercialized (see below).

3.6.2.1 Welded Side Seams

Today in most countries the majority of three-piece tinplate cans used for food have welded side seams. Compared to soldered side seams (see below), welding offers savings in material, since the overlap needed to produce a weld uses less metal than an interlocked soldered seam. As well, the side seam is stronger, it is easier to seam on the ends, and a greater surface area is available for external decorating.

Prior to welding, sheets of steel are enameled, and if necessary printed, with the area where the weld will be made left bare. The sheets are then slit into individual blanks, each blank being rolled into a cylinder with the two longitudinal edges overlapping. The two edges are then welded together.

3.6.2 Three-Piece Can Manufacture

Welded can line

The wire welded operation used today for the high speed welding of tinplate and ECCS containers utilizes a sine wave alternating current (and in the case of tinplate a continuous copper
wire electrode) to produce a weld with an extremely low metal overlap (0.4 – 0.8 mm). The use of copper wire as an intermediate electrode is necessary to remove the small amount of tin picked up from the tinplate during the welding process, which would otherwise reduce welding efficiency. The tensile strength of a good weld is equal to that of the base plate. To prevent traces of iron being picked up by some types of beverages and acidic foods, repair side striping (enameling) of the internal surface of the weld is required.

A system of chemical bonding of side seams has been developed, mainly for dry or otherwise neutral products such as powders and oils. It utilizes a thermoplastic adhesive which is applied to one edge of the pre-heated body blank before it is rolled into a cylinder, giving complete protection of the raw edges of the blank. A strong bonded lap seam is produced that is able to withstand the high in-can pressures generated by beers and carbonated soft drinks during can warming or pasteurization. This method can only be used with ECCS cans since the melting point of tin is close to the fusion temperature of the plastic. However, since the advent of high speed welding operations, the use of chemically-bonded side seams has declined.

3.6.2.2 Soldered Side Seams

Today, with the exception of some developing countries, very few food cans are produced with soldered side seams, the concern of public health authorities being that lead from the tin/lead (2:98) solder would migrate into the food. Since the 1970s, most countries insisted that only pure tin solder be used on cans intended for baby foods, this adding significantly to the cost of such cans. The use of tin/lead solder ceased when the US FDA issued a final rule in July 1995 prohibiting its use in food containers, and now the much more expensive tin/silver (96:4) solder must be used.

Tinplate cans are easily soldered because the tin solder alloy readily fuses with the tin on the surface of the steel. Enamel stripes are sometimes applied to one or both sides of the seam (‘side striping’) in an attempt to repair damage made to the previously applied enamel by the heat of the solder. This is essential on beverage cans and those likely to contain highly corrosive products.

3.6.2.3 Double Seaming

After the side seam has been formed, the bodies are transferred to a flanger for the final metal forming operation: necking and flanging for beverage cans, and beading and flanging for food cans. The can rim is flanged outwards to enable ends to be seamed on. The top of beverage cans is necked to reduce the overall
diameter across the seamed end to below that of the can body wall, yielding savings in the cost of metal through the use of smaller diameter ends, allowing more effective packing and stacking methods to be adopted, and preventing damage to the seams from rubbing against each other.

Simultaneous creation of the neck and flange using a spin process is used. Double-, triple- and quadruple-necking is now quite common, the latter reducing the end diameter from 68 mm to 54 mm for the common beverage can.

For food products where the can may be subjected to external pressure during retorting or remain under high internal vacuum during storage, the cylinder wall may be beaded or ribbed for radial strength. There are many bead designs and arrangements, all of which are attempts to meet certain performance criteria. Basically, circumferential beading produces shorter can segments that are more resistant to paneling (implosion), but such beads reduce the axial load resistance by acting as failure rings.

The end is then mechanically joined to the cylinder by a double seaming operation as illustrated below. It involves mechanically interlocking the two flanges or hooks of the body cylinder and end and is carried out in two stages. In the so-called first operation, the end curl is gradually rolled inwards radially so that its flange is well tucked up underneath the body hook, the final contour being governed by the shape of the seaming roll.

First seaming operation

In the second operation, the seam is tightened (closed up) by a shallower seaming roll.

Second seaming operation
The final quality of the double seam is defined by its length, thickness and the extent of the overlap of the end hook with the body hook. The degree of interlocking between the body hook and cover hook is known as the overlap. It is the amount of overlap that gives the can an hermetic seal, preventing microorganisms from penetrating the can. The body hook and cover hook are both formed by the interlocking of the can body with the can lid. The body hook was originally part of the can body (flange). The cover hook was initially from the can lid. If either is excessively long or short, problems with a short overlap may develop.

The width of the seam is the vertical distance from the bottom of the double seam to its top. An excessive width will also compromise the safety of the overlap. Rigid standards are laid down for an acceptable degree of overlap and seam tightness. The main components of a double seam are shown below:

Finally the cans are tested for leakage using air pressure in large wheel-type testers; leaking cans are automatically rejected.

3.6.3 Two-Piece Can Manufacture

A major innovation in canmaking was the introduction of the seamless or two-piece aluminum can in the 1950s and tinplate can in the 1970s. For many years canmakers have manufactured in a single pressing shallow drawn two-piece containers such as the familiar oval fish can. However, the technology to produce deep drawn cans is a more recent
innovation, although the basic concept dates back to the Kellver system for producing cartridge cases developed in Switzerland during the Second World War.

There are two main methods used commercially to make two-piece cans: the drawn and ironed (D&I) process which can be adapted to produce a can for pressure packs (including carbonated beverages) and for food containers, and the drawn and redrawn (DRD) process which is a multistage operation and produces a can mainly suitable for food products. Both processes depend on the property of the metal to ‘flow’ by rearrangement of the crystal structure under the influence of compound stresses, without rupturing the material.

Two-piece cans have technical, economic and aesthetic advantages in comparison with soldered or welded three-piece cans. In terms of integrity, the two-piece can has no side seam and only one double seam which is more easily formed and controlled because of the absence of a side seam lap juncture. The internal enamel does not have to protect a soldered side seam or weld cut edge, and there are material savings in solder and (in the case of D&I cans) plate, the latter being up to 35% lighter than a standard three-piece can. Since 1970, through the conversion of three- to two-piece cans and subsequent lightweighting, the weight of a tinplate soft drink can has been reduced by 40% to 35 g, and that of the inherently lighter two-piece aluminum can by 24% to 18 g. Technology exists to continue this trend, especially with tinplate cans. Finally, the absence of a side seam permits all-round decoration of the outside of the can, increasing the effective printing area and leading to a more aesthetically pleasing appearance.

3.6.3.1 Drawn and Ironed (D&I)

The D&I (also known as DWI for drawn and wall ironed) tinplate or aluminum container is made from a circular disc stamped from a sheet or coil of uncoated plate and formed into a shallow cup having effectively the same side wall and base thicknesses as the starting material, as shown below. The forming process involves a flat sheet being formed into a cup or cylinder by the action of a punch drawing it through a circular die, the wall thickness of the cup being uniform throughout. The plate is covered with a thin film of water soluble synthetic lubricant prior to forming.
The sequential stages in production of D&I cans.

1. Disc cut from coil
2. Drawn into shallow cup
3. Redrawn into smaller diameter cup
4, 5 & 6. Wall thinning by ironing
7. Trimming to required height

The cup is transferred to an ironing press where it is held on a punch and passed successively through a series of ironing dies. As a consequence of the ironing process, the wall thickness is reduced (typically from 0.30 mm to 0.10 mm) and the body height correspondingly increased. Concurrently the integral bottom end is domed and profiled to provide added strength, the end retaining essentially the original sheet thickness. Because the can wall may not iron to the same height all around the circumference due to slight variation in material properties, cans are ‘overdrawn’ and then trimmed to the correct height.

The trimmed cans are chemically cleaned to remove drawing lubricants and prepare the surface for receiving exterior and interior coatings. If the cans are to be used for beverages, they are then necked; D&I food cans are commonly beaded for added strength against body collapse under partial vacuum conditions. The cans are then flanged.

Tinplate is the best material for D&I cans as the tin coating is soft and ductile and imparts lubricity to the steel while remaining bonded to it throughout. Some aluminum is made into D&I cans for food packaging but these are mainly shallow drawn containers. Most D&I aluminum cans are used for beverage packaging (i.e. beer and soft drinks). ECCS plate is not suitable for ironing as the chromium-based coating is too hard.

### 3.6.3.2 Drawn and Redrawn (DRD)

For many years canmakers have manufactured shallow drawn containers; however, the novelty of the DRD process is the use of multi-stage drawing to produce a can with a higher height-to-diameter ratio. This process is essentially identical to the initial stages of the D&I technique except that the final height and diameter of the container is produced by sequentially drawing cups to a smaller diameter, i.e. causing metal to flow from the base to the wall of the container rather than ironing the container wall. As a consequence, the wall and base thickness as well as the surface area are identical to the original blank, as opposed to the D&I can where the wall thickness is much less than the base thickness. A typical DRD process is illustrated below.

The sequential stages in production of D&I cans.

1. Body blank
2. Drawn cup
3 & 4. Diameter decreases as cup is redrawn
4. Finished trimmed can with profiled base.

Whereas in the D&I process the internal diameter of the body remains constant throughout the ironing stages, the internal diameter of the DRD can is progressively reduced as the height is increased during the various redrawing stages. Therefore, the DRD cans do not offer the same economies as D&I cans because in the former the metal cannot be selectively distributed as it can during wall ironing. Since the end is integral and is normally the thickest region, this governs the material gauge and the result is often excessive side wall thickness. Typically 0.2 mm thickness pre-lacquered tinplate and ECCS is used for the DRD process. DRD cans are currently used in the packaging of food rather than beverages since a greater wall thickness is required to withstand pressure reversals. The body is beaded, and ECCS is used more than tinplate since better enamel adhesion is achieved with the former.

### 3.6.4 Protective and Decorative Coatings

Container coatings provide a number of important basic functions:
- protect the metal from the contents;
- avoid contamination of the product by metal ions from the container;
- facilitate manufacture;
- provide a basis for decoration and product identification;
- form a barrier to external corrosion or abrasion.

### 3.6.4.1 Protective Coatings

Internally enameled (lacquered) metal containers are used when the product and the plain (uncoated) container would interact to reduce the shelf life or the quality of the product to an unacceptable level. Thus acidified beetroot, colored berry fruits, beer and soft drinks are packed in enameled containers, i.e. containers in which organic coatings have been applied to the inside (and sometimes the outside) surfaces.

The primary function of interior can coatings is to prevent interaction between the can and its contents, although some enamels have special properties which allow products such as meat loaf to be easily removed from the cans, while others are used merely to improve the appearance of the pack. Exterior can coatings may be used to provide protection against the environment (e.g. when the cans will be marketed in particularly humid or salt-laden climates), or as decoration to give product identity as well as protection. Generally some external lacquering of tinplate and ECCS containers is necessary for products stored in hot humid atmospheres to prevent external corrosion, particularly at the side seam region for three-piece cans.

For most containers the enamel is applied to the metal in the flat before fabrication, typical film masses being in the range 3-9 gsm (4-12 µm thick). However, because of the considerable amount of metal deformation with substantial disruption of the surface which takes place in the D&I operation, such containers must be coated internally after fabrication.
Where it is essential to minimize product-container interactions, e.g. for canned beer and soft drinks where metal pick-up can affect flavor and clarity, the cans are given a post-fabrication repair lacquering.

Many types of internal enamel are available for food containers. The original can lacquers were based on oleoresinous products which include all those coating materials which are made by fusing natural gums and rosins and blending them with drying oils such as linseed or tung (Chinese wood oil). Although oleoresinous coatings are still used today (largely because of their low applied cost), a move has been made to synthetic phenolic resins dissolved in a blend of solvents.

Sulfur resistant enamels are used to prevent staining of tinplate surfaces by sulfur compounds released from foods such as meat, fish and vegetables which have sulfur-containing amino acids that breakdown during heat processing and storage to release sulfides. These react with tin to form black tin sulfide, or accumulate in the headspace and give out an unpleasant odor. To overcome this problem, two approaches have been used. Enamels are pigmented with zinc oxide or zinc carbonate which reacts with the sulfur compounds to form white zinc sulfide (these are known as the sulfur-absorbing enamels), or the enamels are pigmented with aluminum powder or white pigment to obscure any tin sulfide which might form (these are known as sulfur-resisting enamels).

Special enamels having additives such as waxes to assist the release of the product from the can, or enamels pigmented with aluminum powder or other materials are also used. The latter were described above as sulfur-resisting enamels, but they are also used in premium quality packs where sulfur staining is not a problem, simply to improve the appearance of the inside can surface.

### 3.6.2 Decorative Coatings

Although the primary purpose in decorating the external surface of a metal container is to improve its appearance and assist its marketability, it also significantly improves the container's external corrosion resistance. Decoration of the external surface is similar in many respects to the process used to protect the internal surface, the constituents generally being dispersed in volatile solvents, applied on roller coating machines (apart from the printed image) and baked in tunnel ovens. Offset lithography has been used for over a century for decorating sheet metal.

### 3.7 Aluminum Foils and Containers

#### 3.7.1 Aluminum Foil

Aluminum foil is a thin-rolled sheet of alloyed aluminum varying in thickness from about 4-150 µm. Foil can be produced by two methods: either by passing heated aluminum sheet ingot between rollers in a mill under pressure and then rerolling on sheet and plate mills until the desired gauge is obtained, or continuously casting and cold rolling. This latter method is much less energy intensive and has become the preferred process.
Aluminum foil is available in a variety of alloys. In the softest temper, aluminum foil exhibits dead fold characteristics, i.e. when wrapped around an object it will assume the profile of the object with no springback. While this is frequently advantageous, soft temper foil also wrinkles very easily which necessitates the use of great care during handling.

Aluminum foil is essentially impermeable to gases and water vapor when it is thicker than 25.4 µm, but it is permeable at lower thicknesses due to the presence of minute pinholes. For example, 8.9 µm foil has a WVTR of up to 0.3 mL m⁻² day⁻¹ at 38°C and 100% RH.

Aluminum foil can be converted into a wide range of shapes and products including semirigid containers with formed foil lids, caps and cap liners, composite cans and canisters; laminates containing plastic and sometimes paper or paperboard where it acts as a gas and light barrier; and foil lidding, the latter being sealed using inductive sealing. Processes involved may include converting, forming, laminating, coloring, printing and coating. It can also be embossed to provide textured surfaces.

### 3.7.2 Aluminum Tubes

The collapsible aluminum tube is a unique food package which allows the user to apply the product directly and in precise amounts when required. Typical applications include condiments such as mustards, mayonnaises and sauces, as well as dessert sauces, cheese spreads and pâté.

The aluminum tube is formed by the cold impact extrusion of an aluminum slug using a plunger. To relieve the hardness, the tube is annealed in an oven at 600 °C, after which the inside is enameled with a lacquer. Aluminum tubes are closed by folding after application of a latex or heat sealable lacquer inside the fold area and heat applied; this ensures a hermetic seal. Today the aluminum tube is relatively rare with most food tubes being made of plastic. Although early plastic tubes contained aluminum foil as a barrier layer, it is now common to coextrude LDPE with EVOH to obtain a tube which provides an excellent barrier to air and moisture. Plastic tubes are also printed by a dry offset process.

Plastic barrier laminate (PBL) tubes are used to pack foods, personal care lines and pharmaceuticals. The plastic structure retains its good looks after handling. A five-layer structure includes an ethylene vinyl alcohol (EVOH) barrier layer to protect the contents from oxygen and also prevents oils or volatiles from leaching out of the pack.

### 3.7.3 Retort Pouch

The retort pouch is a flexible package,
hermetically sealed on three or four sides and made from one or more layers of plastic and/or foil, each layer having a specific functionality. The choice of barrier layers, sealant layers and food contact layers depends on the processing conditions, product application and desired shelf life. Typical processing conditions involve temperatures of 121°C for times of up to 30 minutes (60 minutes for the large (3.5 kg) catering packs). One of the attractions of the retort pouch compared to the metal can is the thin profile of the package (12-33 mm for 200-1000 g pouches), enabling retorting times to be reduced by up to 60%, final quality to be improved, as well as rapid reheating prior to consumption. Other advantages include the ease of carrying, reheating and serving, as well as weight and space saving. Finally disposal of the used pouch is much simpler than for the metal can as it can be easily flattened.

It is for all of the above reasons that retort pouches have found wide acceptance by military forces, the US military term for this type of package being 'Meal, Ready-To-Eat' or MRE; "Meals Rejected by Everyone" is a popular nickname for MREs. NASA began using retort pouch food for space missions in the 1970s and the US Army began delivering large quantities of MREs to the troops in 1981.

A typical three layer pouch structure would be an outer layer of 12 µm PET (polyethylene terephthalate) for strength and toughness; a middle layer of 7-9 µm aluminum foil as a moisture, light and gas barrier; and an inner layer of 70-100 µm CPP (cast polypropylene) for heat sealability, strength and compatibility with all foods. An additional inner layer of 15-25 µm PA (polyamide or nylon) is used when a longer shelf life is required.
Traditionally a three-sided seal pouch was used for MREs and other commercial products, but recently a multilayer four-side-seal retort pouch has been developed. Stand-up pouch designs having a gusseted bottom have also been commercialized.

Transparent retort pouches can be produced by replacing the aluminum foil layer with certain plastics that may also have an inorganic coating, thus allowing the pouch to be reheated in a microwave oven.

The shelf life of foods packaged in retort pouches is very dependent on storage temperature. If stored at 16°C, they will last for about 130 months; at 27°C 76 months; at 38°C 22 months, and at 50°C, only a month. Because of this, military MREs are stored in climate controlled warehouses where they can be kept for up to ten years before being used.

### 3.8 Corrosion of Metal Packaging

Metals are chemically reactive and can be readily oxidized by O₂ and other agents to form largely useless corrosion products. This vulnerability to oxidation accounts for the fact that with few exceptions (copper, silver and gold), metals do not occur naturally in the metallic state but are found combined with O₂ or sulfur in their ores. A considerable amount of energy is required to extract metals from their ores, and the reverse process (which releases energy) is strongly favored as the metal reverts back to its natural state. As a very broad generalization it can be said that the more difficult it has been to win the metal from its natural form, the greater will be its tendency to return to that form by corroding, but the rate of return will of course depend on the environment.

#### 3.8.1 Tinplate Corrosion

The tinplate surface consists of a large area of tin and tiny areas of exposed tin-iron alloy (FeSn₂) and steel as a result of pores and scratches in the tin coating. The tin-iron alloy layer acts as a chemically inert barrier to attack on the steel base. In the case of tinplate exposed to an aerated aqueous environment, all the anodic corrosion is concentrated on the minute areas of steel and the iron dissolves, i.e. rusts. In extreme cases perforation of the sheet may occur. This is the process which occurs on the external surface of tinplate containers.

However, inside a tinplate can, the tin may be either the anode or the cathode depending on the nature of the food. In a dilute aerated acid medium the iron dissolves, liberating H₂. In deaerated acidic food, iron is the
anode initially, but later reversal of polarity occurs and the tin becomes the anode, thus protecting the steel; tin has been described in this situation as a sacrificial anode. This reversal occurs because certain constituents of foods can combine chemically with $\text{Sn}^{2+}$ ions to form soluble tin complexes.

As discussed earlier in this chapter, food cans with enamel (lacquer) coatings are used to protect against excessive dissolution of tin, sulfide staining, local etching and change in color of pigmented products such as berry fruits. However, the use of enamels will not guarantee the prevention of corrosion and in some cases may actually accelerate it. Therefore, careful consideration must be given before selecting an enamel system for a particular canned food.

The general pattern of corrosion in enameled cans is very different from that in plain cans, and is generally more complex. It depends not only on the quality of the base steel plate, the tin-iron alloy layer and the tin coating, but also on the passivation layers and the nature of the enamel coating. The only exposure of metal in an enameled can is at pores and scratches in the enamel coating and at cracks along the side seam. Some of these discontinuities in the enamel coating may coincide with pores in the tin coating, thus resulting in exposure of the steel. Even if defects in the enamel film expose only the tin coating, the availability of all the corrosion promoters in the can for attack on the limited areas of tin ensures that steel is soon exposed at them. Because these areas of exposed steel are almost unprotected, corrosion may proceed at a rapid rate, resulting in $\text{H}_2$ swelling or perforation of the can. Thus it is easily possible to actually reduce the shelf life of a canned product by using an enameled can.

### 3.8.2 Corrosiveness of Foods

Food products and beverages are extremely complex chemical systems covering a wide range of pH and buffering properties, as well as a variable content of corrosion inhibitors or accelerators. Factors which influence the corrosiveness of food products and beverages can be divided into two groups: intensity and type of corrosive attack inherent in the food itself, and corrosiveness due to the processing and storage conditions. All these factors are interrelated and may combine in a synergistic manner to accelerate corrosion.

The most important corrosion accelerators in foods include $\text{O}_2$, anthocyanins, nitrates and sulfur compounds. From a corrosiveness point of view, it is convenient to divide foods into five classes: those that are highly corrosive such as apple and grape juices, berries, cherries, prunes, pickles and sauerkraut; those that are moderately corrosive such as apples, peaches, pears, citrus fruits and tomato juice; those that are mildly corrosive such as peas, corn, meat and fish; and strong detinners such as green beans, spinach, asparagus and tomato products. Beverages are conveniently considered as a fifth class.

### 3.8.3 External Corrosion of Cans

Although tinplate is very durable in a
dry atmosphere, it rusts readily in the presence of moisture, rusting occurring more readily the thinner the tin coating. The presence in the atmosphere of sulfur dioxide or oxides of nitrogen accelerates the rate of corrosion since they dissolve to form acids. Chlorides (present in locations close to the sea) can also cause a rapid increase in the rate of corrosion. Rusty cans will not be purchased by consumers even though the contents may be perfectly good.

When cans are water cooled, they should be around 40°C when they are removed from the retort. If they are warmer than this, there is the risk of thermophilic spoilage, chemical degradation and significant internal corrosion; if they are cooler than this, insufficient heat will remain to evaporate any water adhering to the exterior of the can. Cans should be stacked in such a way so as to enable self-drying to occur prior to labeling and packing.

If corrosion is to be prevented during storage, then the atmosphere surrounding the can must be free of corrosive vapors or chemicals, and not promote condensation of moisture. As well, packaging materials in contact with the cans (generally paperboard cartons closed with adhesives) should be as free as possible from soluble chlorides, sulfates or other salts which may promote condensation of moisture and corrosion. Cartons usually have a water content of 10-12%, and when the air temperature rises, moisture evaporates from the cartons in the warmer outer zone and condenses in the cooler center of the stack.

The shrink wrapping of cans, while protecting them from promoters of corrosion found in the atmosphere, can cause problems of condensation. If the air inside the shrink wrap contains a considerable quantity of water vapor and the package is later subjected to a drop in temperature, condensation will occur.

Rusting can also be caused by
unsuitable conditions of transport and storage where cycling of the humidity (described as ‘sweating’) occurs. This is especially so when cans are transported from temperate to tropical areas, or temperate to temperate areas via the tropics (for example, from Australia to North America). Attempts to prevent condensation of moisture by free movement of air have usually been unsuccessful because the center of a stack of cartons filled with cans takes a long time to respond to the external temperature change and may remain below the dew point for long periods.
CHAPTER 4: GLASS PACKAGING

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4.8 Properties of Glass Containers

4.8.1 Advantages
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4.1 Learning Objectives

This module has been written to provide a basic understanding of, and introduction to, glass packaging. On completion of this module, the student will have a general appreciation of the composition and structure plus the physical properties of glass containers. In addition, the raw materials and processes used to manufacture glass containers, as well as aspects of glass container design and glass container nomenclature will also be discussed.

4.2 Introduction

Glass is a combination of sand and other minerals that are melted together at very high temperatures to form a material that is ideal for a wide range of uses from packaging and construction to fibre optics.

Although glass is often regarded as a man-made material, it was formed naturally from common elements in the earth's crust long before the world was inhabited. A form of glass occurs naturally within the mouth of a volcano when the intense heat of an eruption melts sand to form obsidian, a hard, often black, glassy type of stone, the dark color coming from microscopic magnetite grains. Mankind first used this material as tips for spears.

Glass has been defined as ‘an amorphous, inorganic product of fusion that has been cooled to a rigid condition without crystallizing.’

Glass is actually a liquid at room temperature but because it is so viscous or 'sticky' it looks and feels like a solid. At higher temperatures glass gradually becomes softer and more like a liquid. It is this latter property which allows glass to be poured, blown, pressed and molded into a wide variety of shapes.

The two main types of glass container used in food packaging are bottles (which have narrow necks) and jars (which have wide openings). About 75% of all glass food containers are bottles and approximately 85% of container glass is clear, the remainder being mainly amber. Generally, today's glass containers are lighter but stronger than their predecessors, with the weight of many bottles and jars
Glass Packaging

having been reduced by 25-50% over the last 50 years. Through developments such as this, the glass container has remained competitive and continues to play a significant role in the packaging of food and drink.

4.3 Composition and Structure

The basic raw materials for glass making come from mines or quarries and must be smelted or chemically reduced to their oxides at temperatures exceeding 1500°C. The principal ingredient of glass is silica derived from sand, flint or quartz. Silica is combined with other raw materials in various proportions.

- Sand (silica) is the major ingredient in glass
- Alkali fluxes (commonly sodium and potassium carbonates) lower the fusion temperature and viscosity of silica. Calcium and magnesium carbonates (limestone and dolomite) act as stabilizers, preventing the glass from dissolving in water. Other ingredients are added to give glass certain physical properties. For example, lead gives clarity and brilliance although at the expense of softness of the glass; alumina increases hardness and durability.

A typical formula for soda-lime glass would be:
- Silica (sand) 68-73%
- Limestone (calcium carbonate) 10-13%
- Soda ash (sodium carbonate) 12-15%
- Alumina (aluminum oxide) 1.5-2%

4.4 Physical Properties

4.4.1 Mechanical Properties

Because of its amorphous structure, glass is brittle and usually breaks because of an applied tensile strength. It is now generally accepted that fracture of glass originates at small imperfections or flaws, the large majority of which are found at the surface. A bruise or contact with any hard body will produce on the glass surface very small cracks or checks that may be invisible to the naked eye. However, because of their extreme narrowness, they cause a concentration of stress. Since glass cannot yield, when the applied stress is high enough, it causes these flaws to propagate and the container to shatter.

In practice, a stress concentrator may be a small crack or check induced during the manufacturing process, or a scratch resulting from careless container handling. Therefore, the major step taken to make glass more...
break resistant involves the elimination of surface flaws (e.g. microcracks) by careful handling during and after forming and annealing, since the condition of the surface has a great deal to do with its tensile properties. The mechanical strength of a glass container is a measure of its ability to resist breaking when forces or impacts are applied.

The causes of glass container breakage have four important aspects:

a. **Internal pressure resistance** - this is important for bottles produced for carbonated beverages, and when the glass container is likely to be processed in boiling water or in pressurized hot water. Internal pressure produces bending stresses at various points on the outer surface of the container.

b. **Vertical load strength** - while glass can resist severe compression, the design of the shoulder (see figure on p. 17 for details of glass container nomenclature) is important in minimizing breakage during high speed filling and sealing operations.

c. **Resistance to impact** - two forms of impact are important: a moving container contacting a stationary object (as when a bottle is dropped), and a moving object contacting a stationary bottle (as in a filling line). In the latter situation, design features are incorporated into the sidewall to strengthen contact points. The development of surface treatments (including energy absorbing coatings) to lessen the fragility of glass when it contacts a stationary object has been very successful.

d. **Resistance to scratches and abrasions** - the overall strength of glass can be significantly impaired by surface damage such as scratches and abrasions. This is especially important in the case of reduced wall thickness bottles such as ‘one-trip’ single use bottles. Surface treatments involving tin compounds (in conjunction with other treatments) provide scuff resistance, thereby overcoming susceptibility to early failure during bottle life.

Although the mechanical strength of a bottle or jar can increase with glass weight, this is at the expense of thermal strength which decreases with increasing glass weight. Considerable expertise is required by the glass maker to determine the most appropriate design to satisfy the mechanical strength requirements and balance the thermal strength demands of the finished product.

### 4.4.2 Thermal Properties

The thermal strength of a glass container is a measure of its ability to withstand sudden temperature changes. In the food industry, the behavior of glass with respect to temperature is of major significance, because relative to other forms of food packaging, glass has the least resistance to temperature changes. The resistance to thermal failure depends on the type of glass employed, the shape of the container, and the wall thickness.

When a glass container is suddenly cooled (e.g. on removal from a hot oven), tensile stresses are set up on the outer surfaces, and compensating compressional stresses on the inner
surface, as shown below:

Conversely, sudden heating leads to surface compression and internal tension as shown below:

In both situations, the stresses are temporary and disappear when the equilibrium temperature has been reached. Because glass containers fracture only in tension, the temporary stresses from sudden cooling are much more damaging than those resulting from sudden heating, since the potentially damaged outside surface is in tension. It is found in practice that the amount of tension produced in one surface of a bottle by suddenly chilling it is about twice as great as the tension produced by suddenly heating the other surface, assuming the same temperature change in both cases.

Thermal shock resistance is required of all types of glass containers that have to withstand sudden temperature changes (thermal shock) in service such as in washing, pasteurization or ‘hot pack’ processes, or in being transferred from a warmer to a colder medium or vice versa. Resistance to breaking is determined by transferring glass containers which have been totally immersed in a hot water bath (typically at 63°C) for 5 minutes to a cold water bath (typically at 21°C) and observing the number of breakages.

4.4.3 Optical Properties

The optical properties of glass relate to the degree of penetration of light and the subsequent effect of that transmission, transmission being a function of wavelength. Transmission may be controlled by the addition of coloring additives such as metallic oxides, sulfides or selenides. For example, the presence of iron oxide in glass produces a green color; cobalt oxide produces a blue color; and manganese and nickel oxides produce a purple color.

4.5 Manufacture

4.5.1 Mixing and Melting

The largest constituent (68-73%) of a typical soda-lime glass is silica; the second largest constituent (15-50%) is cullet (i.e. scrap or recycled glass), originating both as glass scrap from the factory and recycled glass from consumers. Although the use of cullet can cause problems with the production of some types of glass
unless there is good separation of colored glass and removal of associated material such as labels, the use of cullet is economically desirable since less energy is required to melt cullet than new raw materials. Cullet also reduces the amount of dust and other particulate matter that often accompanies a batch made exclusively from new raw materials. Although the total primary energy use decreases as the percent of cullet rises, the maximum energy saved is only about 13%.

Cullet is scrap or recycled glass

The raw materials are weighed, mixed and charged into a glass-melting furnace which is maintained at a temperature of approximately 1500°C. Here they are converted into molten glass that is chemically homogeneous and virtually free of gaseous inclusions (bubbles). The melting process consists of two phases: changing the solids into a liquid, and the fining or ‘clearing up’ of the liquid. During the refining process, gases (principally CO₂, SO₂ and water vapor) produced by the chemical reaction rise to the surface of the furnace and are removed. When the molten glass becomes free of gas (seed-free) it is then ready for forming into containers. It moves from the furnace into the working end of the furnace (mistakenly called the refiner) where thermal homogenization and cooling of the glass to the viscosity required for the particular operation begin. At this point the temperature of the melt has been lowered from 1250-1350°C to approximately 1100°C.

4.5.2 Forming Processes

The glass is carried from the working end of the furnace to the forming machine in a channel-like structure called a forehearth which is fired by a number of small burners, the aim being to ensure uniform temperature distribution throughout the depth of the glass. At the end of the forehearth is a gob-forming mechanism consisting of a rotating sleeve and vertical plunger. The glass exits in a continuous, viscous stream which is cut by rapidly moving, horizontal steel blades (shears) to form what is known as a ‘gob’, i.e. a mass or lump of molten glass.

Individual section forming machine

Precise control of temperature and shape during the formation of the gob is required for the high speed production of accurately formed glass
containers, temperatures in the vicinity of 1100°C varying by no more than ±1°C being typical.

The process of converting a cylindrically shaped gob of glass into a bottle or jar is called forming, and it is essentially a controlled cooling process. Various types of forming machines are used throughout the world, the predominant type being the IS (individual section) machine. As its name implies, it consists of up to 16 sections, each one an individually functioning, hollow glass machine. It performs two basic functions: it shapes the gob into a hollow container and simultaneously removes heat from the gob to prevent it from deforming significantly under its own weight.

Two basic types of processes are used to make containers on the IS machine: the blow-and-blow (B&B) and the press-and-blow (P&B). A closure size of approximately 35 mm is the dividing line between narrow-neck B&B containers (i.e. bottles) and wide-mouth P&B containers (i.e. jars).

4.5.2.1 Blow and Blow (B&B)

Bottles are normally produced by a two-step ‘blow and blow’ process as shown below whereby a gob of glass, accurately sheared in terms of weight and shape, is dropped into an externally air-cooled cast iron cavity known as the parison or blank mold. Some of the glass flows over a plunger in the base of the mold which is used to mold the finish of the container by means of ring molds. Compressed air is applied to force the glass down onto the plunger to form the neck ring. Sometimes vacuum is applied from the bottom as an alternative or additional procedure.
When the finish molding is complete, the plunger is retracted and air blown in from the bottom, enlarging the size of the bubble until the glass is pressed out against the blank mold to form a hollow preform. This is then inverted and transferred to the blow mold where it elongates under its own weight. Air at about 200 kPa or vacuum is applied so that the glass is pressed against the metal surface of the blow mold which is air cooled to ensure rapid removal of heat. The mold is then opened and the fully blown parison (now at approximately 650°C) removed and held over a deadplate for a brief time to allow air to flow up through the deadplate and around the container to further cool it. It is then transported to the annealing lehr.

4.5.2.2 Press and Blow (P&B)

In the case of jars, a two-step ‘press and blow’ process is used as shown below. The body blank or parison is formed by pressing the gob of molten glass against the mold walls with a large plunger. When the cavity is filled, glass is then pushed down into the neck ring and the finish is formed. No baffle or counter-blow air is used in the formation of the parison cavity, the operation relying on the mechanical introduction of the plunger into the glass. The rest of the steps in the P&B process are identical to those in the B&B process.
4.5.2.3 Narrow Neck Press and Blow (NNPB)

In this more recent process for lightweight bottles, the gob is delivered into the blank mold and pressed by a metal plunger. The plunger and gob together have the same volume as the blank mold cavity. This enables the glass maker to decide exactly how the glass is distributed in the parison and, hence, to be able to more accurately control the uniformity of glass distribution in the finished container; weight savings of up to 30% can be made. The second stage is
similar to the B&B process. The parison is blown to a finished container having a more uniform wall thickness and, as a result, higher strength.

(almost the softening point of the glass), holding it there for a few minutes and then cooling at a rate which is consistent with the removal of stress from a predetermined wall thickness.

The critical area of temperature is between the upper annealing point (softening point) and the lower annealing point, after which they may be cooled at a rate which enables them to be handled as they emerge from the lehr.

### 4.5.3 Annealing

The term annealing generally refers to the removal of stress, the annealing temperature or point being defined as the temperature at which stresses in the glass are relieved in a few minutes. The containers are transferred from the deadplate to a large oven known as a lehr which is equipped with a belt conveyer.

During cooling the inside surface is hotter than the outside; this results in compression on the outer surface but tension at the inner surface. As mentioned earlier, glass fractures only in tension and usually at the surface. Sudden cooling introduces tensile stresses into the outer surfaces and compensating compressional stresses in the interior. Poorly annealed containers may be subject to breakage if the tension is high or the inner surface is bruised.

The function of the annealing lehr is to produce a stable product by removing any residual stresses resulting from non-uniform cooling rates during forming and handling. This is achieved by raising the temperature of the container to approximately 540°C.
4.5.4 Inspection

When glass container emerge from the annealing lehr, each one is inspected for faults. They are then packed in outer containers or palletized and dispatched to the warehouse.

4.5.5 Surface Treatments

The strength of a newly-made glass container can be rapidly reduced by moisture or abrasion, and some form of surface treatment to increase the strength is essential, since glass is non-lubrious. Two general types of surface treatment are applied to glass containers to modify mechanical properties.

4.5.5.1 Hot End Treatment

In this treatment (typically carried out while the glass container is 550°C) vapor containing tin or titanium (generally in the form of a tetrachloride) is brought into contact with the outside of the container, forming a thin film of metal oxide. This treatment prevents surface damage while the container is still hot, strengthens the surface and improves the adhesion of the subsequent cold-end coating.

4.5.5.2 Cold End Treatment

This treatment (typically carried out while the glass container is less than 100°C) is designed to protect the container surface and assist its flow through the filling line. Typically it involves spraying an organic material in an aqueous base containing either waxes, stearates, silicones, oleic acid or polyethylene onto the outside of the container to increase its lubricity by providing a surface with a low coefficient of friction. It is important to check the compatibility of the cold end treatment with any adhesives used to attach labels. Sometimes only the cold end treatment is applied.

4.5.5.3 Shrink Sleeves

Although not strictly related to surface treatment of glass containers, shrink sleeves will be considered here since they can have an important influence on the formation of imperfections leading to container breakage due to surface contact. Most shrink sleeves are made of oriented plastic films that shrink around a glass container when heat is applied. Two types of protective labels are used on glass bottles in the form of a body sleeve: one constructed from thin, foamed PS (polystyrene), the other made from uniaxially oriented PVC (polyvinyl...
or PS. The former offers some thermal insulation, while the latter (which can completely wrap the bottle from its neck to underneath the base if desired) contains the glass fragments and prevents shattered glass being scattered in all directions if the bottle is dropped.

4.5.6 Defects in Glass Containers

Some sixty defects can occur in finished glass containers, ranging from critical defects such as ‘birds-wings’ and ‘spikes’ (long, thin strands inside the container that would probably break off when the container was filled) to minor defects such as ‘wavy appearance’ (an irregular surface on the inside). Defects are classed as critical if they are hazardous to the user and make the container completely unusable; major if they reduce the usability of the container or its contents, and minor if they detract from its appearance or acceptability to the consumer.

Accurate classification of defects in glass packaging and their commercial significance are areas of specific expertise and no attempt will be made to describe or catalog them here.

4.6 Glass Container Design

One of the major advantages of glass as a packaging material is its capability to be formed into a wide range of shapes related to specific end uses, customer requirements and aesthetic appeal. The commercialization of CAD/CAM (computer-aided drafting and computer-aided manufacture) techniques has made the task of designing new glass containers considerably easier and more rapid. This has lead to greater flexibility in design and manufacture, and resulted in considerable efficiencies through a more thorough analysis of stresses and strength/weight factors and calculation of likely mechanical performance.

4.7 Glass Container Nomenclature

The basic nomenclature used for glass containers is shown below. Usually the shape of the container is determined by the nature of the product, each product group having a characteristic shape. Thus liquid products generally have small diameter finishes for easier pouring; solid products require larger finishes for filling and removing the contents. As well as filling and emptying requirements, consideration must also be given to the nature and manner of labeling the container, and its compatibility with packaging and shipping systems.
The container finish (so-called because in the early days of glass manufacturing, it was the part of the container to be fabricated last), is the part of the container that holds the cap or closure, i.e. the glass surrounding the opening in the container. It must be compatible with the cap or closure and can be broadly classified by size (i.e. diameter), sealing method (e.g. twist cap, cork, etc.), and special features (e.g. snap cap, pour-out, etc.).

The finish has several specific areas including the sealing surface which may be on the top or side of the finish, or a combination of the two; the glass lug which is one of several horizontal, tapering and protruding ridges of glass around the periphery of the finish on which the closure can be secured by twisting; the continuous thread which is a spiral projecting glass ridge on the finish intended to mesh with the thread of a screw-type closure; a transfer bead which is a continuous horizontal ridge near the bottom of the finish used in transferring the container from one part of the manufacturing operation to another; a vertical neck ring seam resulting from the joining of the two parts of the neck ring, and a neck ring parting line which is a horizontal mark on the glass surface at the bottom of the neck ring or finish ring resulting from the matching of the neck ring parts with the body mold parts. Not all glass containers have transfer beads or vertical neck ring seams.

Although there are literally hundreds of different finishes used on glass containers, glass finishes are standardized and a specific set of dimensions, specifications and tolerances has been established for every finish designation by the Glass Packaging Institute (GPI) in the USA and equivalent bodies in other parts of the world.

Once a design has been accepted, the molds used in the manufacturing process must be made. They are usually constructed of cast iron and consist of three parts: a bottom plate, a body mold (divided vertically into two halves), and a neck or finish mold which is also usually split into two parts. Because of the high cost of mold manufacture, changes to container size and shape are usually made only if large quantities of the container are required. Generally, customers select their containers from the standard range provided by glass manufacturers unless they are extremely large users in which case the extra expense of customized designs is justified.
4.8 Properties of Glass Containers

4.8.1 Advantages

- Chemical inertness
- Impermeable to gases and vapors
- Brilliant clarity
- Rigidity
- Resistance to internal pressure
- Hygienic
- Heat Resistant

Glass containers have brilliant clarity

4.8.2 Disadvantages

- Fragile
- Dense (2.4 g/cm\(^3\))
- Limited color availability
- High energy demand for manufacture

Glass containers are fragile

4.9 Exercise

a. Discuss the main advantages and disadvantages of glass from a consumer’s perspective.

b. Discuss two important forms of impact resistance in glass containers.

c. Compare and contrast hot-end and cold-end treatments in glass bottle manufacture.

d. List the various temperatures encountered during a typical glass manufacturing process.

e. Describe the finish on a glass container and explain why it is important.

f. Discuss the advantages of shrink sleeves on glass containers.

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