2 Categories and Subclasses of Packaging Materials

2.1 Metal Packages

In recent years, the market of food packaging materials (FPM) has evolved into a multitude of new solutions. At the same time, food producers have created different products in relation to every known food category. Technological researches have a specific weight. However, marketing strategies and the natural orientation of the ‘normal consumer’ have to be considered according to Moskowitz and co-workers [1].

The main objective of Chapter 2 is the description of different food packaging types, from the oldest solution to ultimate possibilities. The so-called metal can is the oldest packaging for food preservation and one of the distinctive pieces of evidence of the modern Industrial Age. Actually, this is the viewpoint of several detractors.

In effect, metal cans are generally linked with a glorious era of past technological enterprises. In recent years, the metal packaging field was considered [2, 3] too static because of the sensation of ‘reached maturity’ or market saturation. For this reason, the main objectives of metal can producers seemed circumscribed to the optimisation of productive results and the reduction of stored raw materials. This tendency has to be interpreted as the consequence of the lack of important non-metal packages in relation to mechanical resistances and high barrier properties (Section 5.3).

Today, the situation appears different, although several observers forecast bad news for the sector of metal cans. Several interesting innovations have been designed and created in recent years with reference to self-heating and self-cooling cans (Section 2.1.11). Other innovations concern new shapes and different sizes for metal cans on the basis of consumer science studies. Generally, new graphical configurations derive from other materials such as plastic bottles that are linked to well-established brands. Finally, the continuous growth of the beverage market seems to give good perspectives to the production of aluminium cans according to recent research [4]. On the other hand, the evolution of paper and plastic packages may damage canmakers in the future, according to Meissbach [5].

Exclusively concerning metal packaging, the following list shows the most important applications according to Oldring and Nehring [6]:

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- Three-piece cans, general use.
- Two-piece ‘drawn and wall ironed’ (DWI) cans, for beverages.
- Two-piece ‘drawn and redrawn’ (DRD) cans, for solid foods such as salmon fish.
- Two-piece ‘single drawn’ cans, for canned foods and ready-to-eat meals.
- Two-piece ‘drawn and ironed’ cans, for non-carbonated beverages.
- Can ends (classic, easy-open and easy-peel types).
- Aerosol containers (three-piece and two-piece cans).
- Flexible tubes, for fluid foods.
- Closures: crowns (normal and twist-off types).
- Closures: vacuum lug (twist-off® and push-twist types) closures.
- Closures: aluminium closures (for bottles).
- Closures: lids, for dairy products.
- Semirigid cans for coupled packages.
- Drums and pails.
- Trays and foils.

Different productive methods can be adopted in relation to these categories. This chapter should help food operators (FO) to comprehend used packages and their possible defects. Consequently, the author proposes the following approach in this chapter:

- General discussion about FPM and food applications.
- General discussion about productive methods.
- Detailed exposure of main packaging failures with one or more safety implications, in accordance with the Hazard Analysis and Critical Control Points (HACCP) approach.

Before starting with the first point, a premise should be made in relation to metal packages. All consumers are aware of the metallic nature of tin cans and similar containers, but very few people are conscious of their hybrid nature. In other words, metal cans should be considered as plastic containers because of the presence of polymeric coatings with the addition of brilliant inks and protective paints. Actually,
every metallic container shows typical metallic advantages (and disadvantages) with other positive and negative factors related to plastic. As a result, metal containers may be defined as the most complex package in respect of other categories because of the variety of failures and related causes.

### 2.1.1 Three-piece Cans

These packages correspond to the preferred mental image of the normal consumer because of strong traditions in regional influences and recognised links with a famous artist (Andy Warhol and his acclaimed *Campbell’s Soup Cans*). However, the tin can is now completely different from the original containers. In detail, the thickness of raw materials (laminated tin-coated steel, *Section 3.5*) has been continually reduced because of economic constraints with a consequent improvement in mechanical resistances by means of the introduction of body beads (three-piece cans for tomato soups).

The structure of a normal three-piece can is shown in [Figure 2.1](#).
Essentially, six elements need to be mentioned [6]:

1. The can body: This cylinder corresponds to a coated sheet. After coating, this laminate (wall) is rolled and the seam is welded. The body is directly responsible for the total mechanical resistance. Sometimes, this resistance is improved with the creation of several lines that are perpendicular to the main axis of obtained cylinders. These lines are not obligatory but can lighten all expected tensions caused by the total weight of superimposed containers into final pallets.

2. Can ends: Distinctive elements are several concentric lines that have been obtained by pressure so that one end may be considered as the hypothetical union of ‘expansion panels’. This stratagem makes possible the extension by volumetric increase of the whole can and consequent dilatation of ends during pasteurisation and sterilisation procedures. Expansion panels are not compulsory.

3. Internal and outer coatings: All components (body and ends) have to be coated with some particular exceptions (general line cans, for vegetable oils), but the coating processes are different and temporarily extended until the forming and seaming steps (Section 2.1.12).

4. Polyvinyl chloride (PVC) gaskets into ends: Indeed, top and bottom ends cannot assure the hermetic seal of the final can without this rubber product.

5. The correct seaming of the can body and ends: This operation – called double-seaming – is extremely important and is dependent at least on the dimensions of flanges and end curls. Double-seaming is managed by canmakers (top ends) and FO (bottom ends only).

6. The side seam: This welding is electrically carried out on two opposite sides of the coated laminate (wall). It has to be highlighted that these sides are partially uncovered so that two opposite and equal areas (solder margins) are obtained. In fact, these operations cannot be carried out on coated surfaces. The obtained side seam is coated with thermosetting products (epoxy phenolic coatings, white enamels) with to protect against acid agents and other degrading effects. As a result, the global thickness is not constant in this area.

From a general viewpoint, three specific categories of three-piece containers can be illustrated:

- ‘General line’ cans.
- Three-piece metal cans without body beads.
- Three-piece cans with body beads.
‘General line’ containers are designed and produced for vegetable oils and similar foods (Figure 2.2). These cans are uncoated on the inner side because the edible content is not considered aggressive, with the exception of degraded (acid) oils. The can body is smooth while the related ends can be produced in two ways: smooth and perforated with the aim of inserting plastic caps (Figure 2.2).

Figure 2.2 A typical ‘general line’ can

Three-piece metal cans without body beads are destined to the following uses:

1. Canned vegetables (peas, mushrooms, similar food preparations, and so on) with different weights and dimensions.

2. Canned sauces: Tomato juice, spicy recipes (paprika, harissa and other Maghreb recipes, and so on).

3. Salted snacks (peanuts, almonds, and so on).
5. Meat-based foods (chopped pork, cooked ham, meats in jelly, and so on).
6. Avicultural products.
7. Oriental recipes (surimi and other fish-based food products such as soups of carps and soyabean, and so on).
8. Canned fish (tuna fish, salmon, crabmeat, and so on).
9. Luxury brands (coffee and cocoa powders, and so on).

All these applications do not necessarily require body beads. Moreover, printed images and related protective coatings on the outer side may be extremely damaged and every mechanical deformation has to be carefully evaluated. Several models are produced with non-rounded ends (Figure 2.3).

![A three-piece metal can without beads, rectangular base](image)

**Figure 2.3** A three-piece metal can without beads, rectangular base
Categories and Subclasses of Packaging Materials

Three-piece cans with body beads are expressly designed and produced for canned foods with strong resistance to high weights and particular storage conditions. Because of the distinctive preference of tomato canneries, these containers are highly linked to related sauces.

With regard to can ends, the importance of so-called easy-open ends (EOE), (Figure 2.4) in respect of conventional open top (OT) models has to be highlighted. These ends are apparently similar to normal types but their distinctive feature is the presence of an attached pull tab. In fact, the distinction between these ends and other closures is the possibility of easy opening without using a can opener. From a general viewpoint, it can be stated that:

a. Laminated material can be electrolytic tin plate (ETP), tin free steel (TFS) or aluminium alloys (Section 3.5.4).

b. The pull tab, aluminium- or steel-made, has to demonstrate good resistance when joined with the expansion panel.

c. The easy opening can be ensured with an incision on the surface of the end. After this superficial cut, every end has to be immersed in an electro-conductive coating, of the epoxy phenolic type (Section 3.5). The aim is to obtain the electro-deposition of this coating on the incision within 5–10 seconds by means of the metallic nature of the ends; a sort of electrode. Generally, the epoxy phenolic coating is very visible because of its yellowish tint and different clarity with relation to other varnishes (Figure 2.4).

d. Finally, EOE are seamed by packaging operators (PO) while FO can only seam bottom (normal) ends.

2.1.2 Two-piece Single Drawn Cans

These traditional containers (Figure 2.5) are generally linked to canned seafood (anchovies, sardines, and so on) and ready-meal products. Dedicated EOE are required for this type of container. It has to be remembered that internal and external coatings have to be accurately chosen because of very notable tensions on the bottoms of cans.
Figure 2.4 EOE

Figure 2.5 A typical two-piece single drawn can
2.1.3 Two-piece Drawn and Wall-ironed Cans

DWI containers have been always associated with soft drinks and alcoholic beverages [4, 6]. However, it has to be highlighted that the continuous tendency to the reduction of productive costs has modified the world of DWI cans in relation to design and employed raw materials. Originally, aluminium coils were extensively used to produce two-piece cans. Recurrent economic crises and the continuous increase of aluminium prices have encouraged PO also to use steel materials. It can be inferred that the use of steel is connected with economic depressions in the aluminium industry.

Figure 2.6 shows the most well-known features of these containers:

a. Inner and external sides are completely coated, similarly to three-piece cans.

b. The double-seaming is extremely important (top end only).

c. This container does not require body beads.

d. The apposed end, a ‘stay-on-tab’ type (SOT), is provided with an incorporated tab (Figure 2.7). Questions were raised in Italy ten years ago in relation to old SOT closures (Figure 2.8) and the potential risk of physical damage (possibility of foreign bodies on the outer side and transportation into the beverage after opening). This difficulty has been solved by new SOT types (Figure 2.7). However, ‘old’ ends may be seen on certain cans at present.

e. SOT ends have to be produced with more rigid materials than those used for can bodies. In relation to aluminium cans, the quantity of magnesium is progressively increased (0.8–1.3% to 4–5% in 2001) when manganese has shown an opposite trend according to Lorusso and co-workers [3].

In addition, it should be noted that:

1. By the technological viewpoint, DWI cans are manufactured and assembled differently from three-piece containers. Concerning the latter type of cans, bodies and related ends are coated before the final assembly. By contrast, the bodies of two-piece containers may be obtained by aluminium coils and successively coated. The same thing occurs when ETP coils (Section 3.5.2) are used. The final assembly does not show complications since the closure is coated without printed images.

2. From an aesthetic viewpoint, two-piece DWI cans are perceived as innovative packages in comparison with three-piece containers (‘old-fashioned’ products).

Another consideration has to be highlighted about the opportunity of different materials for the same package. Concerning tin-coated steel, also called ETP, the design and production of two-piece cans was seriously considered in the 1990s as the
answer to high prices of aluminium. Related experiments have been carried out with
notable economic efforts and different types of commercialised packages. However,
several results have not been fully approved because of the difficulty in obtaining
flexible cans by conventional ETP materials. After many years, the situation in the
aluminium market has not substantially changed in the direction of affordable prices
for manufacturers. Consequently, non-aluminium DWI cans have been proposed again
with different results depending on the request of national markets.

Figure 2.6 A typical two-piece DWI can
Figure 2.7 SOT ends, modern version

Figure 2.8 SOT ends, ‘old’ version
2.1.4 Two-piece Drawn and Redrawn Cans

Drawn and redrawn packages (Figure 2.9) correspond to a subcategory of two-piece cans except for the particular shape. In fact, the general appearance seems to link these cans to traditional three-piece containers. In addition, the manufacturing process – including coating and pressing – is similar. On the other hand, differences concern raw materials: tin free steel (TFS, Section 3.5.3) can be replaced with aluminium with excellent results because of the high flexibility.

Figure 2.9 A typical DRD can
In recent years, this type of package has been seen as the ‘old’ choice by consumers because of the destination: meat and meat-based preparations, seafood in oil, and so on. Nowadays, DRD cans have obtained good results (‘a renaissance’, according to several FO) because of two motivations:

1. The introduction of new ready-to-eat products (tuna fish in traditional spicy curry, and so on), promoted as regional recipes (meat and chilli, and so on). Clearly, marketing strategies have their role.

2. The creation of easy-peel ends (EPE). These hybrid materials, obtained from plastic laminates and metal (Figure 2.10), are one of the most important reasons for the success of ready-to-eat foods.

Figure 2.10 Peelable closures
The manufacturing process of DRD cans requires excellent raw materials (ETP, aluminium) concerning flexibility and ductility because of the particular ‘drawing’ step (Section 2.1). Coatings and inks are requested to exhibit analogous mechanical features.

### 2.1.5 Flexible Tubes

Aluminium materials and plastics are extensively used to produce flexible tubes (Figure 2.11). These cylindrical containers are sealed on one side and closed by a screw cap on the other side. Different applications are possible:

1. Anchovy paste and other transformed fish products.
2. Different food pastes (mayonnaise, spicy sauces, and so on).
4. Regional recipes.
5. Other spreadable foods.

![Figure 2.11 A common flexible tube](image)
Flexible tubes have obtained good results because of the easy use and different destinations (ready-to-eat foods, ‘trendy’ and highly processed products, toothpaste applications, and so on). For example, anchovy pastes are preferred by young consumers in comparison with traditional anchovies in oil (preferred packages: glass jars, single drawn [SD] cans).

The introduction of screw-up caps must be remembered. This argument has to be reprised in relation to plastic packages (Section 2.2).

### 2.1.6 Aerosol Containers

These three- and two-piece cans are designed to contain and release immediately fluid products by aerosol dispersion.

Raw materials are ETP for three-piece containers and aluminium alloys for two-piece (Monobloc) cans [6]. In reference to the latter package, the following features should be noted (Figure 2.12):

1. Inner and external coatings are spray-applied after the forming process.
2. The can body is produced by impact extrusion and top closures show the characteristic ‘ogival shoulder’. These features have the aim to provide excellent mechanical resistance against inner pressures.

### 2.1.7 Kegs

These containers are produced and destined to contain notable quantities of beverages (up to 50 litres). The similarity of kegs to normal three-piece cans is due to the particular shape. Apart from this, the manufacturing process is very different. In fact, such containers are obtained in the following way:

1. Two stainless hemispheres are initially drawn.
2. The drawn pieces are seamed.
3. Finally, two handles are attached to the can body.

From a specific HACCP viewpoint, it should be considered that the continuous and repeated usage of kegs may be questioned because of possible problems derived from imperfect sanitisation after first fillings.
2.1.8 Aluminium Foils and Roll-on Closures for Bottles

These products are extensively used for household and industrial applications. Aluminium is very suitable for the production of high-barrier (impenetrable) coils
and foils. In addition, these materials can be coupled with many plastic films with the aim of obtaining very resistant ends and other objects.

The high resistance to drawing treatments allows aluminium to be employed for the production of high-use articles: semirigid and rigid trays. This application is probably the most diffused product with the exclusion of coupled packages. The manufacturing process of these products is explained in Section 2.1.12.

Roll-on closures, typically destined to be used for bottles for spirits, can be ‘pilfer-proof’ or ‘non pilfer-proof’, depending on the possibility of removal without evidence of the opening, as reported by Oldring and Nehring [6]. Different subtypes may be produced – insertion of PVC gaskets, two-coating systems as epoxy phenolic and vinyl products, PVC liners – depending on the requested contact with foodstuffs and possible thermal treatments.

### 2.1.9 Crowns

These closures are well known because of their strict association with glass bottles. In fact, crowns are generally connected to particular brands (beers, soft-drinks, alcoholic beverages) and can represent notable interests in the market of memorabilia. For this reason and because of the continuous increase in the use of plastic containers, recent years have been difficult for these closures. However, new twist-off crowns are expected to invert this tendency [6].

From the technological viewpoint, the manufacturing shows some similarity to the production of ends for three-piece containers. Before considering the productive process in detail (Section 2.1.12), the following features have to be highlighted (Figure 2.13):

1. The use of ETP and electrolytic chromium-coated steel materials (Sections 3.5.2 and 3.5.3) depends on the required flexibility.
2. Different coatings have to be used depending on the type of metallic support and the supposed ductility of final products.
3. Food-contact sealing inserts are absolutely required [6] to assure hermetic sealing (PVC plastisol, polyethylene or ethylene and vinyl acetate copolymers).
2.1.10 Twist-off Closures

Twist-off closures (TOC) are directly connected with glass containers and the market of preserved foods [6]. In detail, the use of TOC articles is required when opening dimensions are not compatible with glass bottles for beverages (Figure 2.14).

The preferred raw materials are TFS foils (Section 3.5.3) since the metallic support has to be drawn and screwed. The main destinations are:

1. Tomato sauces, spicy products, champignon and other mushrooms in brine, and so on.
2. Orange juices and similar beverages (concentrated and normal products).
3. Dry and semidry products (powdered coffee, potato chips, peanuts, and so on).

Nowadays, the greater part of these closures is produced with a particular push-twist (PT), or safety button, device. The aim is to show premature openings or volumetric increases in glass containers after gaseous fermentations by Clostridium botulinum and other anaerobic bacteria. In addition, PVC gaskets are required to assure the hermetic sealing.

Another interesting application was introduced several years ago with the use of PVC-based oxygen scavenging plastisols (OSP) on the inner side of caps. These substances
are able to adsorb all residual oxygen into the closed container. With reference to hermetic sealing, OSP and normal PVC gaskets for easy-open ends have a similar effect. However, it has to be remembered that the performance is related to a well-known time limit because OSP tend to be irreversibly saturated.

OSP materials are fine PVC dispersions of chemical oxygen scavengers. These agents are mineral salts of reduced metals (zinc, iron [Fe], manganese). Related performance can be good in moist atmospheres because of the easy oxidation of these metals. On the other hand, all scavengers may show some disadvantages. Apart from the problem of high costs, metallic closures and PVC scavengers may suffer physical deformations because of the diminishing O$_2$ pressure in packaged containers. As a result, adequate additives have to be inserted in the final formulation with careful attention to the release of chemical residues and related safety problems [6]. Additionally, PVC gaskets have to be formulated with hydrochloric acid scavengers (possible risk of hydrogen chloride formation). Moreover, indistinct variations may be revealed concerning packaged foods and their smell. Finally, the possible formation of trace amounts of semicarbazide from azodicarbonamide has to be mentioned, according to Oldring and Nehring [6]. Because of these risks, the Directive 2004/1/EC introduced several restrictions on the use of certain plasticisers (Section 3.1.2) in PVC gaskets for vacuum closures [6].

Other interesting innovations concern the introduction of CO$_2$ and the consequent adsorption of oxygen by means of the insertion of iron carbonates and ascorbic acid into the polymeric matrix.
OSP and other scavengers are described in detail in relation to active packaging materials in Section 2.5.

2.1.11 Self-heating and Self-cooling Cans (Metallic and Plastic Chambers)

These containers have evolved from three-piece cans with self-heating or self-cooling mechanisms. Related beverages are very popular with young people because of the possibility to consume many types of cold or hot beverages in any place and situation.

Concerning self-heating cans (SHC), metal containers hold a plastic chamber (Figure 2.15) instead of the classic end. This chamber is subdivided into two compartments and the common plastic wall is easily breakable. Accidental contact with hot beverages is avoided by means of a metallic plate and the visible base consists of a plastic or metallic end with an external ‘heating button’ (Section 2.1.10). The first of two compartments, in direct contact with the end, contains a known quantity of CaO while the second area is filled with normal water.

The aim of this structure is to obtain an exothermic reaction in the plastic chamber as follows:

1. Pressure of PT heating button on the end.
2. Fracture of the plastic cover between two areas and dissolution of CaO in water.
3. Exothermic reaction (production of calcium hydroxide) and heating of the liquid solution;
4. Heating of the metal plate in contact with the beverage.
5. Scalding of the liquid into the container in a few seconds until a maximum and predetermined value.

Other substances can be used to obtain similar effects.

Self-cooling cans (SCC) are similar to the container described above, but the initial pressing on the ‘cooling button’ has to provide an endothermic reaction. Consequently, other reagents or different placements have to be studied (copper sulfate and zinc). Several models have been produced with the insertion of a thermo-adsorbing agent between two compartments while all other components remain unchanged.

Different systems can obtain the same results by means of inert gases in dedicated serpentine minerals [7].
In this situation, refreshing effects are obtained by simple gaseous expansion. As a consequence, there is a variety of possibilities with consequent increase in potential HACCP risks.

Another possible disadvantage – clearly congenital and inevitable – is the reduction of so-called ‘empty spaces’ in SHC and SCC packed containers. This limitation concerns the declarable quantity of beverage but it is clearly tolerated by beverage producers.

2.1.12 Technology, Production and Failures of Metal Packages

This argument cannot be clearly comprehensible without solid bases (chemistry, science of materials, engineering). In relation to this point, it has to be noted that every packaging category is linked to a variety of different machines that are constantly employed to carry out slow or fast steps with crucial importance. Consequently, packaging technologists should:

1. Hold different competencies.
2. Know the right sequence and the importance of operations that are involved in the manufacturing of the container or separated parts.

3. Comprehend all tacit warnings and signals that are originated by ‘out-of-control’ processes.

Consequently, every person without these minimum requirements is obliged to classify the science of packaging in this manner: ‘Clearly difficult and probably indecipherable’. This approach can be the current opinion of many FO, including food technologists. For this reason, the author has decided to provide a restricted list of basic elements about manufacturing processes.

On the other hand, all potential HACCP risks that are directly or indirectly linked to the manufacturing of FPM have to be highlighted. As a consequence, every possible failure of FPM with HACCP connections relating to the manufacturing step will be explained and discussed in detail. In relation to employed raw materials and their features, the reader often will be invited to consult Chapter 3. This approach has been maintained in the same way in relation to FPM types.

The manufacturing of metal packages is differentiated depending on the particular type of container. As a result, understanding the different productions can be extremely difficult at first glance.

With reference to the first category (Section 2.1.1), the manufacturing steps may be summarised in the following way, except for can ends:

a. Reception, quality control (QC) and storage of raw materials: metal sheets or coils, coatings, inks, and so on.

b. Coating step: metal sheets are coated with different varnishes and inks on one or two sides. Several steps are required. One drying oven is required to perform all coating operations (Section 3.1.4).

c. Cutting step: coated sheets are cut to obtain a number of rectangular laminates (walls) that are destined to become the can body. Two sides of these walls – so-called ‘solder margins’ – are not coated and correspond to side seam areas in the final can body (Figure 2.1).

d. Side seaming step: walls are rolled and uncoated sides are welded to obtain can bodies.

e. Side seam striping step: this subprocess is carried out immediately after the side seaming step. The aim is to protect the side seam line with ‘gold’ epoxy phenolic coatings or white enamels (Section 3.1.4).
f. Rolling step: can bodies are mechanically processed to obtain top and bottom flanges.

g. Beading step (optional process): can bodies may be mechanically processed to obtain body beads.

h. Double-seaming step with conventional OT ends or EOE (bottom ends are seamed by FO only).

i. Palletisation, wrapping and final delivery.

The coating step – one of the most critical points in this process – is subdivided in the following way:

1. Preliminary transit of metal sheets into the drying oven (box or conveyor types; temperature, 200 °C) with the aim of eliminating fatty oils on metal surfaces (Section 3.5.2).

2. ‘Inner side’ cycle: application of one (or two) coats of coloured varnishes or enamels (Section 3.1.4) on the ‘inner side’ of the future can. The coating process is well conducted if the whole surface is covered, with the exception of solder margins.

3. ‘Outer side’ cycle, ‘start’ step: application of the following coatings (Section 3.1.4): sizecoats or coloured enamels. The coating process is well conducted if the whole surface is covered, with the exception of solder margins.

4. ‘Outer side’ cycle, intermediate step. Printing process: deposited inks (Section 3.1.4) can be dried in the drying oven or by ultraviolet (UV) rays.

5. ‘Outer side’ cycle, ‘end’ step: Application of the so-called ‘finishing’ varnish (Section 3.1.4) on coated and printed areas, except for solder margins.

The manufacturing of three-piece aerosol containers is similar to the process above, with the exception of the double-seaming step. With reference to two-piece cans, also called ‘monobloc’ containers [6], aluminium materials are subjected to impact extrusion, so that the process is different.

Concerning the production of ends, the manufacturing follows the same general process, except for the coating process because of the necessity to obtain circular pieces instead of rectangular shapes. Coated sheets are cut in two steps to form expansion panels under pressure. Finally, the obtained ends are double-seamed to can bodies with attention to the superposition of related flanges and beads.
Easy-open ends are provided with (1) a tab that is fixed on the outer side and (2) a superficial incision. The extreme importance of this incision should be noted because of potential risks concerning the removal of coatings from the protected surface. With reference to this problem, the inner and outer incisions are coated once more by means of an electrophoretic process and the deposition of plastic resins on electroconductive and uncovered points. This application is possible if the cut ends are deposited on electroconductive surfaces, so that future EOE can become collectors of electric charge. Other spray-coating processes are possible.

In recent years, a new hybrid and easily peelable system has been created for different uses. Easy-peel ends are obtained by joining a classical metal end without its central area and a coupled plastic/aluminium film. The adhesion is the most important factor in relation to EPE.

Two-piece SD cans are different from traditional three-piece containers because of the particular shape. It should be highlighted that can bodies are obliged to tolerate high tensions on four 90° angles. Consequently, this problem concerns the stability and related features of metal sheets and coatings. In detail, the success of the manufacturing process depends mainly on (1) the adherence of coatings and inks to metal sheets and (2) the ductility or flexibility of polymeric chains (Section 3.1.4).

DRD containers differ from three-piece cans because of the intrinsic structure. In fact, the body is already produced with a circular piece by means of strong mechanical pressure at high speed. As a result, the impact is very violent and various portions of plastic coating may be removed. Used coatings and enamels have to be extremely strong with reference to flexibility, ductility and peel resistance. After this step, can bodies can be double-seamed with ordinary or peelable ends.

Crowns and TOC are obtained with procedures that are similar to the production of OT ends and SD cans. For this reason, these packages are not discussed here in detail.

Concerning two-piece DWI cans, the manufacturing is radically different:

a. Cutting step: lubricated aluminium or tin plate coils are cut to obtain circular pieces called ‘initial cups’ (related thickness: 0.25–0.35 mm).

b. Forming step: metal cups are drawn.

c. Reforming and wall-ironing step: drawn walls are redrawn and stretched with the aim of obtaining resistant bodies.

d. Trimming step: can bodies are cut on the top so that the same height is obtained.

e. Washing step: can bodies are intensely washed.
f. Outer coating and printing steps: cans are coated and printed on the outer side. Processed cans are dried in dedicated ovens [8].

g. Flanging and beading steps: the tops of the aluminium cans are flanged; several circular beads are formed on can bodies [8].

h. Inner cycle-coating step: cans are spray-coated on the inner side.

i. Double-seaming step: ends are joined to can bodies.

j. Palletisation, wrapping and final delivery.

Flexible tubes are extruded from a slug of metal, usually aluminium [6]. Intermediate tubes are seamed on the bottom and internally coated if this protection is requested. The final step is the external coating.

Finally, the manufacturing of semirigid aluminium trays can be summarised in the following way:

a. Production of aluminium-made coils with adequate thickness. This step is actually a long succession of various passages and the complete description is not really helpful for FO. The main goals of this succession are (1) the progressive reduction of the initial thickness (3–8 mm) to 0.035 mm and (2) obtaining flexible and deformable coils. It has to be considered that obtained thicknesses can be progressively reduced if intermediate coils are compressed between opposite lamination rollers. This compression has to be repeated many times under alternate conditions (‘heat’ or ‘cold’ lamination) with the addition of anti-friction water/lipid emulsions. These emulsions are eliminated by heating. In addition, obtained coils are superficially degreased with aqueous solutions containing acid or alkaline substances and surface-active agents. Final washing procedures allow master coils to be obtained. Aluminium coils for domestic applications are obtained in this way.

b. Tray-forming step: master coils are cut and prelubricated with food-contact approved oils. Intermediate pieces are then drawn by means of particular presses. The use of lubricant substances is absolutely necessary to normalise the distribution of deformations on the whole surface. In addition, formed trays may adhere to metal presses with possible damage caused by improper separation.

Following this synthetic description about the manufacturing of metal packages, all important defects and failures can be discussed with related HACCP implications. All failures related to metal cans and all packages examined in Chapter 2 are indicated with an acronym: PFnn, where PF is for ‘packaging failure’ and ‘nn’ is a progressive number. This identification has been introduced here to make the individuation and clarification of several practical situations easier (Chapters 6, 7, 8 and 9).
2.1.12.1 PF01 Failures of the Metallic Support

These defects are strictly dependent on the nature (production, storage, QC) of laminated sheets and coils. One of these situations is the emergence of unusual alternating stripes on the inner side of metal cans. These lines are caused by the use of low-cost tin plates. The original name of this material is ‘coke’ (Section 3.5.1). Clearly, the imperfection concerns the aesthetic appearance of cans and is dependent on the local quantity of deposited tin (Sn). On the one hand, tin is deposited on steel sheets and coils with the aim of protecting metallic supports against oxidant agents. On the other hand, the emergence of these stripes on the inner side of metal cans after coating processes can indicate a variability in the superficial resistance to corrosion. In fact, local deficiencies of tin on certain points and the accumulation on other areas may lead to possible and predictable corrosions.

Should raw materials be damaged by corrosion, the adhesive properties of inner coatings would be compromised. As a result, final cans could show a quantity of uncovered points on the inner side and the consequent contamination of food products. This situation is serious when acid foods are packaged into damaged cans [6, 9].

This failure and similar imperfections may be visually corrected. However, one coat of conventional varnish is not sufficient. Generally, two coats of ‘gold’ epoxy phenolic products are requested because of (a) the intrinsic transparency and (b) the compromised adhesion of deposited and polymerised coatings. Alternatively, a good ‘covering’ of white enamels may be used on condition that the final colour is white enough and average quantities of enamel per m$^2$ are elevated. The adhesion of coatings is not related to the appearance of metal cans and may be compromised.

Another defect is the appearance of black or brown spots on coated surfaces. This situation is similar to the problem discussed above and is caused by local accumulation of tin. In fact, the imperfection should not be discussed from an HACCP viewpoint because black or brown accumulations are completely covered and the polymerisation (reticulation) of plastic films is not influenced. However, it has to be remarked that tin isolated masses may be insecurely attached to metallic surfaces. Every polymeric network could be damaged on these points because of possible metallic removals.

Another classical failure of metal sheets and coils is ‘polygonalisation’ (Section 8.1). This phenomenon is caused by the unconventional orientation of laminated sheets during the coating process [10]. Laminated sheets have to be coated while in motion and the direction has to coincide with bright and small lines on metal surfaces (these traces originate in the laminating process). Otherwise, rectangular walls – future can bodies – will probably suffer evident fractures on surfaces with removal of tin, ruptures of polymerised networks and consequent corrosion. This phenomenon is
called polygonalisation because of the excessive hardness (Section 5.4) of laminated materials in the above-mentioned direction. As a result, coated and uncoated sheets tend to form a cylindrical body with polygonal bases. Each hypothetical vertex of these bases corresponds to two possible linear fractures (inner and outer surfaces) on can bodies at the same time. The defect is easily observable with the so-called hardness test (Section 5.4). Additionally, tin plate materials and other low-cost steel sheets may show the same situation under normal conditions (correct coating direction) because of excessive rigidity along the x- and y-axes. Once more, this problem may be avoided with a common hardness test.

2.1.12.2 PF02 Drawing Failures

The manufacturing of two-piece DWI and DRD cans requires an essential step, called drawing. Concerning this complex operation, metal supports have to be protected to avoid all possible mechanical and aesthetical damage. The best solution is the use of adapted lubricants. Critical factors are the choice of these substances and the continuous control of related quantities. It has to be considered that these lubricants are completely eliminated in drying ovens. Consequently, all drawing defects related to insufficient amounts of lubricants can be classified as (a) mechanical damage, (b) superficial scratches and (c) corrosion on broken and uncovered surfaces.

2.1.12.3 PF03 Coating Failures

These imperfections are a well-distinguished category for various reasons. With the exclusion of problems related to the erroneous formulation of coatings (PO cannot control this process), all failures related to the incorrect coating step have to be examined in detail. The mixing of different fluid components is extremely important in relation to the formulation of coatings (coloured pastes, UV brighteners). One situation concerning different imperfections can be described here. This case concerns the production of metal cans when the inner side is coated with two components: ‘gold’ epoxy phenolic paints (Section 3.1.4) and whitening agents (zinc oxide paste, produced with epoxy phenolic resins). This mixture is employed for metal cans that are destined to contain sterilised tuna fish in olive oil or other liquid fats [6, 9]. This food and other products (sardines, lima beans, and so on) with a high percentage of sulfurred amino acids tend to release hydrogen sulfide (H₂S) after sterilisation. This acid is able to penetrate polymerised networks (epoxy phenolic films) and react with tin until the production of black tin sulfide, is visible.

This appearance (sulfur blackening) is easily correctable with the addition of zinc oxide (ZnO) to epoxy phenolic resins and the consequent production of white zinc
Food Packaging and Food Alterations: The User-oriented Approach

sulfide [9]. The obtained mixture, originally an oleoresinous product (Section 3.1.3), is generally called ‘C enamel’ [9]. However, the solution above may be a serious risk. ZnO pastes – 50–70% ZnO and oleoresinous resins [9] – tend to accumulate amorphous masses of epoxy phenolic resins when stored in cold warehouses with the possible catalysing action of zinc. Consequently, the addition of similar ZnO pastes to acceptable ‘gold’ resins may produce the following failures: (a) microbubbles, (b) partially covered craters originated by microbubbles after drying and (3) visible wrinkles on the coated surface. These imperfections are very serious because of the limited thickness of deposited coatings near bubbles, concavities and wrinkles. On the other hand, bubbles can be mechanically broken. Additionally, each crater or bubble is able to release partially active intermediates to contained foods.

Cold storage is not the only negative factor about chemical additives. In fact, excessive thermal values over 20–25 °C may cause ‘prepolymerisation’ (premature reticulation of resins, Section 3.1.4) with consequent precipitation of partially amorphous agglomerates on the bottom of drums. As a result, the addition of heated ZnO pastes to normal ‘gold’ coating may produce these failures: (a) bubbles, (b) craters, (c) wrinkles and (d) so-called dewettings or eyeholings (diffused presence of uncovered points on large areas, see Chapter 5).

All these failures may be explained considering the importance of rheology in the coating process. The viscosity of paints has to be checked and maintained constant during all coating substeps. This parameter influences other variables: applied weight of coating per square metre, drying conditions, and so on. The presence of resin agglomerates in chemical additives and resulting coatings is extremely dangerous because it modifies the viscosity of paints (fluctuating values for heat-stored resins, continuous increase for cold-stored resins). Consequently, the rheological control of coating processes becomes very important and a correct dilution with chemical solvents may be needed to reach acceptable viscosity values. Otherwise, the coating process can be defined as ‘out-of-control’ and should be suspended or terminated. The control of viscosity is important in a number of different procedures (coating, printing) and concerns the application of dissimilar products (resins, inks, casein glues, adhesives).

Other coating defects concern the use of thixotropic products with reference to white enamels and other coloured products. Thixotropy is the coexistence of two different density values for the same fluid. In other words, certain coatings can be fluid when stirred or shaken and return to the semisolid state upon standing. Consequently, static and dynamic viscosities do not have identical values. Because of the critical importance of rheological control, all dense coatings have to be continually monitored. The most simple situation is offered by white enamels. These products consist of plastic resins and inorganic pigments (Section 3.1.4). This mixture tends to spontaneously
agglomerate and continuous application in a long process (up to six hours) can be difficult because of the fluctuation of viscosity values. Related failures are similar to the defects discussed above.

In relation to dewettings, the importance of the correct coating quantity has to be considered. This parameter is expressed as grams of liquid or dry coating per $m^2$ of surface. Generally, high liquid weights before drying determine good or acceptable dry weights. As a result, metal supports should be completely covered. On the other hand, low liquid weights correspond to low dry values and metal surfaces are imperfectly coated. In other words, the applied resin is unable to cover all the available area because of unfavourable surface tension values. Therefore, a number of microscopic pinpoints remain uncovered after drying and solvent removal. This phenomenon may be corrected in two ways: (a) increase of liquid weights per $m^2$ with attention to viscosity increases and (b) suspension of dilution with adapted solvents if viscosity values are already too high (microbubbles).

Another failure is related to off-set printing techniques (a brief description of this method is available in Section 2.3.1.3 on PF25) and the possible partial removal of inks on non-assigned zones. This defect is called ‘bleeding’ and will be reviewed in the following sections in the discussion of different printing techniques. A typical example of bleeding is displayed in Figure 2.16.

Finally, the so-called ‘reticulation’ of coatings has to be controlled. This word corresponds to (1) the evaporation of organic diluents, and (2) the subsequent polymerisation of plastic resins. Concerning all coating types (Section 3.1.4), the composition is normally heterogeneous and the plastic fraction consists of partially polymerised products that are ready to complete their reticulation in convenient conditions. For example, ‘gold’ epoxy phenolic resins need to be heated at 200–205 °C (10 minutes). Different parameters (too low temperatures, reduced times) can affect the chemical structure of reticulated networks in relation to chemical properties (resistance to acid substances, penetrability, and so on) and mechanical features (adherence, flexibility, and so on). In addition, bad reticulation performance (Section 5.5.3) implies that Sn and Fe (metal support) are open to corrosive attacks. The reticulation can be voluntarily carried out at low temperatures with the objective of obtaining partially active coatings. These ‘meta-resins’ are able to react with other similar plastic products and this circumstance is used to apply two coats on the same side. The so-called ‘delayed polymerisation’ – epoxy phenolic coatings: 1st coat: 170 °C, 2nd coat: 200 °C – is a direct application of the principle expressed above. The first of these passages is also called ‘blocking’.
2.1.12.4 PF04 Failures Related to Superficial Adhesion

Coatings and enamels are organic substances from the chemical viewpoint. On the other hand, metallic supports are clearly inorganic and this means they have a very different chemical nature in comparison to organic (plastic) matter. Organic chemists maintain that chemical substances are well dissolved by similar molecules. Consequently, metallic substances and carbon-based molecules should not be easily linkable by means of chemical bonds or similar interactions. However, strong or acceptable adhesions of organic coatings on metal sheets and coils can be explained with the superficial presence of metals such as Sn and chromium (Cr). The first substance is deposited on steel coils with the aim of protecting surfaces from superficial oxidation. In addition, chromium is the residual trace of normal procedures known as ‘passivation’ (Section 3.5.2). These metals are strongly inclined to interact with free carbonylic groups (organic resins) because of the presence of six (Cr) or four (Sn) free atomic orbitals [11]. The higher the maximum oxidation number, the higher the number of atomic orbitals that can interact with carbonyl groups. Therefore, the presence of chromium on metallic supports is a clear advantage for adhesion.
However, these metals may not be sufficient to obtain good supports. In other words, the superficial adhesion is dependent on supports and coatings at the same time. The following succession of coated films on a normal tin plate sheet can explain this point.

White enamel/three conventional inks/finishing (transparent) coating can be good or unsuccessful depending on the control of viscosity and other parameters (PF03). The following factors may damage all the multi-layered system and compromise the adhesion: low or high viscosity, prepolymerisation or low quantity of wetted coating per square metre.

Other problems can occur:

a. Chemical incompatibility between the enamel and deposited inks (these components have to cover selected zones on white plastic supports).

b. Chemical incompatibility between inks and the finishing varnish (the last component has to cover all zones).

c. Superposition of different inks on the same zone and possible chemical incompatibility.

d. Excessive water quantity in the wetting liquid emulsion (this water/oil system guarantees the correct transfer of inks on selected zones in the so-called off-set technology, Section 2.3 on PF24).

One or more of these possibilities can affect the chemical stability of this multi-layered structure. As a result, the $n^{th}$ component or layer is not strongly adherent to the inferior layer and the structure is similar to a building without solid foundations.

2.1.12.5 PF05 Side Seam Failures

These defects may be caused by incorrect seaming on solder margins (Section 2.1.1). These zones are purposely uncoated (Figure 2.1). In the so-called side-seaming step, the welding of margins is electrically conducted and the seamed line is conveniently protected with ‘side seam stripe’ coatings. This substep can be carried out with spray or roller technologies. In the first method, a liquid coating is pumped directly on the side seam. In the second procedure, analogue coatings are transferred on to the side seam by a steel roller. In addition, white powdered products can be used with excellent results instead of conventional side seam stripes. In this situation, a coating gun is needed to charge polymeric powders with the consequent deposition and subsequent drying (300 °C, time < 60 seconds).
With reference to side seam defects, the simplest situation is the incorrect welding with consequent combustive burst of organic traces (coatings, enamels) on solder margins. Note that disjointed margins can be corroded by acid food substances. Because of their plastic nature, these coatings may be hydrolysed with acid-catalysed mechanisms in the same way as other defective polymers, according to Scheirs [12]. This defect is very visible because of the emergence of black burns on the side seam with an unusual crater-like appearance.

Another case is so-called ‘blistering’. This means the formation of bubbles on the side seam [13]. This situation can be easily explained considering the low viscosity of side seam stripe coatings. In effect, the defect is analogous to the coating failures discussed above. It should be noted that related failures appear after sterilisation only. These ‘delayed’ bubbles appear a second time because of the insufficient reticulation (PF02) in the side seam striping step. This point has to be highlighted since several claims about canned acid foods concern local corrosion and the consequent presence of linear coloured protuberances in the immediate proximity of solder margins. The incorporation of water molecules in this zone after sterilisation is an important variant (PF08).

2.1.12.6 PF06 Other Superficial Imperfections on Beaded Cans

All coated can bodies may be mechanically damaged. In the so-called rolling step, can bodies are processed with the aim of obtaining two rolled flanges (upper and lower positions). A neck can be produced before the formation of flanges with the objective of piling intermediate bodies. Additionally, several circumferential deformations (body beads) may be produced with the aim of increasing mechanical resistances under considerable pressures. Concerning this step, modified can bodies may show numerous microscopic fractures of coating films on beads. This failure is generally caused by the wrong choices being made about coatings and/or enamels (insufficient mechanical resistance; low auto-lubrication; low quantity of liquid coating per m²). Related failures are connected with chemical and physical features of coating components (see Section 3.1.4).

2.1.12.7 PF07 Double-seaming Failures

The double-seaming step is one of the most critical parts of the whole manufacturing process. Excellent or good seamings may depend on different factors, but the main problem remains the correct superposition of end curls on flanges of the can body [6]. Notably, this step is always carried out by FO and will not be explained here.
In relation to this step, an erroneous overlap always determines the non-hermetic sealing of final cans. On the other hand, double-seaming may be imperfect with optimal superposition values [6, 10]. Should this situation be evident, the state of PVC gaskets deposited into the ends has to be checked in relation to physical appearance and applied weights (Figure 2.1). This plastic is a precautionary measures against possible damage caused by incorrect superposition, but their performance is strictly dependent on the deposited quantity per single end, the correct drying and the rheological state of liquid products. In addition, the control of applied weights has to be considered in relation to liquid and dry PVC matter. These data are strictly connected (PF02).

### 2.1.12.8 PF08 Sterilisation Failures

Generally, these imperfections are similar to coating failures (PF03, PF04, PF05) but their evidence depends strictly on the contained food and the thermal procedure of preservation. Firstly, the incipient and progressive corrosion of metal cans in different points with a random distribution has to be remembered. This case includes all situations with exploded microbubbles and dewettings under acid attack. An interesting variant is linked to side seam stripe blistering (PF05) and concerns the insufficient or inadequate reticulation of coatings and the consequent penetration of red and orange pigments from contained foods. Therefore, metal supports are easily corroded while the presence of microbubbles and microcraters is evident. In other words, these defects may be recognised and employed to draw a ‘corrosion risk’ map on the whole surface of metal cans (body and ends). In addition, metal supports can be attacked in other ways. One of the most well-known situations is called ‘meshing’ and corresponds to the penetration of coloured natural pigments (carotenoids, erythrosine, and so on) into the polymeric matrix of coated films. This phenomenon allows these substances to penetrate into molecular vacancies of plastic networks (generally epoxy phenolic resins and white enamels). The related failure should not be extremely dangerous but can become evident if:

a. Low quantities of wetted coating are deposited; and/or

b. Reticulation rates are not optimal; and/or

c. Applied coatings contain plasticisers in excess (see Section 3.1.2).

Additionally, meshing effects are made worse after sterilisation. This discussion is important from the HACCP viewpoint because of the following questions: ‘What about any metal can that is able to absorb natural substances in such a macroscopic way? Is this container able to easily interact with the contained food?’ Should these answers be positive, ‘What do metal cans give to the foods contained therein regarding
changing natural pigments?” Meshing is macroscopic evidence of the chemical migration in two directions: from metal support and polymeric networks to foods via molecular vacancies and vice versa. An interesting variant of the defect can occur without coloured pigments on inner and external (printed) sides after sterilisation. In this situation (‘white meshing’), metal containers show diffuse water microbubbles incorporated into coated surfaces (Figure 2.17).

![Diagram of multilayered system and water penetration](image)

**Figure 2.17** White meshing on metal cans. Structure of multilayered systems and water penetration

Another sterilisation failure is the problem of adhesion. However, this defect concerns the apparent increase of adhesive forces under drastic conditions in the presence of acid foods.
Finally, the grotesque phenomenon called ‘ghosting’ has to be mentioned [14]. Ghosting, also called ‘set-off’, is the appearance of printed images on the inner side of metal cans. A more precise definition of set-off is reported by Forrest [15]. With reference to the characteristics of this defect, these inner images correspond to the negative impression of external printings and become evident after sterilisation. Actually, ghosting is not exclusively related to metal packaging. Other situations have already been discussed in recent years. The most well-known situation is the migration of a photoinitiator for UV inks – so-called ‘isopropyl thioxanthone’ (ITX) – from coupled packages (the inner side) to contained foods (milk). It should be considered that the ITX situation has not been revealed by macroscopic defects. In this situation and other similar cases (metal cans) the main cause is the erroneous (partially blocked) polymerisation of inner cycle coatings with successive deposition and adhesion of outer cycle-UV inks by simple contact.

Negative images may remain masked if the inner coating is similar to deposited inks (‘gold’ coating and yellow or orange ink). However, drastic thermal treatments can burn organic pigments and make evident the hidden image on the inner side.

Most parts of metal containers and other printed materials are generally subjected to different movement and storage options. In relation to storage, metal sheets have to be temporarily deposited ‘in pile’ after the conclusion of every coating substep. Consequently, each partially coated metal sheet may transfer one or more coating components – including inks – to the opposite face of upper or lower foils by simple contact, because of (1) estimated high weights and (2) insufficient reticulation of inner side coatings (they are very able to react with active polymers – see Figure 2.18.

2.1.12.9 PF09 Reduced Flexibility

This failure concerns aluminium coils, two-piece cans, rigid and semirigid trays and other flexible materials. Concerning heat lamination processes, metallic materials are preheated (550–600 °C) with the objective of homogenising aluminium and other alloy components [16]. With reference to this multistep process (the lamination is a succession of hot and cold passages), critical variables are thermal values and process times. Should these parameters be out of control, different microscopic defects (metallic dislocation) can occur. In other words, laminated materials are not homogeneous (high presence of aluminium in certain molecular clusters and consequent lack in other zones). Macroscopically, laminated alloys can show poor ductility values in certain sections of the uninterrupted coil. The resistance of laminated materials is strictly dependent on the synergic sum of melting and repeated lamination steps (Section 2.1.12). Poor flexibility means the possibility of microscopic and/or visible fractures on packaging surfaces.
Printed logo, outer side

Ghosting effect: inner side (Eposyphenolic coating)

Figure 2.18 Ghosting in metal cans
2.1.12.10 PF10 Inclusion of Organic and Foreign Materials

This failure is related to all types of lamination processes (aluminium, ETP, TFS, and so on). With reference to the manufacturing of aluminium coils, lamination steps require the dispersion of water/lipid emulsions. Generally, lubricant and refrigerant mixtures contain pharmacopoeia-grade Vaseline and medicinal Vaseline oils [17].

These substances may be liquid or semisolid. Alternatively, synthetic or natural esters can be used. Lubricant mixtures have to be guaranteed against:

1. Oxidative rancidity according to EN ISO 6886:2008 (Metrohm Rancimat® test: time ≥ 100 hours; temperature: 100°C).
2. Possible modification of foods and related organoleptic properties [16].

Otherwise, partially oxidised lipid molecules might be included in metallic surfaces. This aesthetic defect is shown when differently coloured pinpoints are present on surfaces and their removal is not possible. Lubricant oils used before forming operations (rigid and semirigid aluminium trays) are defined as ‘technologically coadjuvant’ concerning current food legislation in the European Union.

2.1.12.11 PF11 Other Superficial Imperfections on Aluminium and Steel Coils

Exclusively concerning high-barrier aluminium coils for household use, the presence of numerous and irregular pointed defects (microcraters and incisions) may be noted with the following features (Figure 2.19):

a. most parts of microcraters are apparently placed in succession on ideal lines.
b. the above-mentioned lines are parallel to laminating traces.
This situation is well known and is caused by:

1. Irregular and pointed deposits on used (exhausted) lamination rollers; and/or
2. Blocked lamination rollers; and/or
3. Speed differences between coils and rollers; and/or
4. Irregular and pointed deposits on original aluminium coils.

Consequently, metallic coils may show superficial irregularities with the risk of microscopic holes because of the simple impression of these foreign bodies. One of the most well-known cases concerns aluminium boxes and the related forming step (presence of foreign bodies on exhausted rollers and low-lubricated coils). Alternatively, metallic impurities or related oxides (amorphous aluminium oxide [Al₂O₃], and so on) may be present on surfaces with possible removal and fractures.

The same defects can be observed on ETP or TFS coils and sheets. In fact, a number of different failures may be ascribed to metal supports, but the argument may appear too complex in reference to our purposes. As a result, the reader is invited to consult specialist papers and handbooks on metal supports and the related technology.
Categories and Subclasses of Packaging Materials

2.2 Plastic Packages

Plastic materials can be widely used to obtain a variety of objects, including FPM. The impressive penetration of these substances in the market of containers is a distinctive feature of modern industrial societies.

<table>
<thead>
<tr>
<th>Food packaging category</th>
<th>Food and beverage applications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Macrocategory: rigid packages</strong></td>
<td></td>
</tr>
<tr>
<td>Cups, boxes, trays and other single-use containers</td>
<td>All foods and beverages</td>
</tr>
<tr>
<td>Expanded polystyrene boxes and trays</td>
<td>Vegetables, seafood, meat, and so on</td>
</tr>
<tr>
<td>Rigid, semi-rigid, transparent and coloured bottles</td>
<td>All liquid foods</td>
</tr>
<tr>
<td>Barrels and 5–20 litre containers</td>
<td>All liquid foods</td>
</tr>
<tr>
<td>Multi-use and reuse boxes</td>
<td>General use</td>
</tr>
<tr>
<td><strong>Macrocategory: flexible packages</strong></td>
<td></td>
</tr>
<tr>
<td>Thermoretractable and extensible films</td>
<td>Vegetables, seafood, meat products, and so on</td>
</tr>
<tr>
<td>Plastic films that are destined to become coupled packages</td>
<td>Polycoupled packages - See Section 2.2.2</td>
</tr>
<tr>
<td>Wrapping films</td>
<td>Vegetables, fish, meat, and so on</td>
</tr>
<tr>
<td>Industrial bags</td>
<td>All foods and additives</td>
</tr>
<tr>
<td>Single-use bags</td>
<td>All foods</td>
</tr>
<tr>
<td><strong>Macrocategory: accessory packages</strong></td>
<td></td>
</tr>
<tr>
<td>Caps</td>
<td>All fluid foods</td>
</tr>
<tr>
<td>Hybrid (plastic/metallic) ends</td>
<td>All foods - see Section 2.1.11</td>
</tr>
<tr>
<td>Other packages</td>
<td>All foods</td>
</tr>
</tbody>
</table>

Plastic packages are virtually unlimited concerning new models, innovative designs and possible evolutions. As a result, it is very difficult to discuss all aspects related to this sector. In relation to the main objectives of this book (HACCP failures and
related genesis), two categories of plastic packages are discussed in detail with the aim of providing interesting examples and a guide for all types of plastic FPM without theoretical considerations. Other possibilities and models are displayed in Table 2.1 with related destinations. The basic and essential contents of this matter are related to chemical and technological features of employed raw materials. Because of the necessity to understand all aspects of plastic packages in a simple and comprehensible way, these arguments are discussed separately in Section 3.1.3.

### 2.2.1 Polyethylene Terephthalate Bottles and Non-coupled Containers: Technology, Production and Failures

Nowadays, FPM are subdivided into a variety of containers, materials and shapes. Exclusively in relation to beverages, the so-called ‘plastic bottle’ (Figure 2.20) joins all these aspects except for flexible and coupled containers (Section 2.2.2). In fact, plastic bottles are generally made of one single raw material: polyethylene terephthalate (PET) (Section 3.1.3).

![Figure 2.20 A common PET bottle](image)
Categories and Subclasses of Packaging Materials

Figure 2.20 shows three essential elements:

1. The cylindrical-like body, adaptable to a variety of uses and users: in relation to external surfaces, it may be produced in different ways: completely smooth, grooved or a combination of two possibilities. Smooth and grooved surfaces are produced with careful consideration to presumable uses with the main objective to obtain good resistance to sudden impacts and permanent mechanical tensions. Formed bottles tend to increase their volumetric capacity within three or four days from the formation because of internal polymer tensions. The formation of bottles implies that obtaining metastable networks and new favourable structures from the thermodynamic viewpoint is possible. In addition, PET bottles may be requested to support inner expansions after bottling (carbonated waters and other soft drinks).

2. The bottom: this part is normally produced with a particular shape for two reasons: (a) obtaining stable packages in comparison with similar glass containers and (b) the particular process of formation. This procedure, called ‘stretch blow moulding’ [18], is briefly discussed in this section with other plastic processes. The total height of PET bottles is related to dimensional parameters (diameter, shape) of the bottoms.

3. The cap: this closure is produced in different sizes and types. Two recent and different innovations have obtained good market results because of the insertion of an anti-hiccup valve or scavengers (consult Section 2.1.10 concerning active materials).

On the other hand, there are five evident problems:

a. The required transparency: UV rays can damage contained beverages in several ways and colourless packages may not be recommended for soft-drink applications (orange juices, and so on).

b. The migration of CO₂ (carbonated water and soft-drinks) from beverages to external bottle surfaces throughout PET walls within three to four days after bottling. Several studies estimate this loss may reach 0.04 volumes per week according to Lorusso and co-workers [3]. This phenomenon is caused by pressure differences between inner and external bottle surfaces.

c. The presence of undesired compounds in beverages (acetaldehyde and other PET oligomers).

d. The possible destabilisation of polymeric structures (Section 3.1.2). This phenomenon, also called ageing, depolymerisation or time alteration, can be accelerated by abnormal thermal values, UV light, CO₂ migration and residual
catalyser residues into the PET matrix. The final result is the progressive modification of PET surfaces with a worrying loss of transparency (opacity) and possible emergence (syneresis) of plasticisers and mineral fillers from the inner polymeric structure to plastic surfaces.

e. The diffusion of atmospheric oxygen. This risk is mainly discussed in relation to normal beverages (without added gases). However, the role of oxygen scavengers when inserted into caps has to be considered. These devices may function as flow collectors for external oxygen. Consequently, contained beverages may be altered and/or inner pressure may diminish with collapsing and possible fractures on tensioned angles.

Generally, the manufacturing of plastic containers that are similar to PET bottles is extremely diversified and heavily influenced by chemical properties of different polymers. The production of plastic containers is essentially a transformation of raw materials (moulding, injection, and so on) without chemical modifications except for rare situations. As a result, raw materials can determine the success or negative results of containers, and packaging producers can operate few amendments. Consequently, the reader should be familiar with organic chemistry and polymerisation procedures. This information, which is necessary to comprehend all implications of the different processes, should justify a separate chapter. However, FO do not really need this detailed information. Consequently, all chemical and technological properties of different polymers are briefly discussed in Chapter 3.

The majority of plastic containers may be considered to be similar to PET bottles with reference to manufacturing, except for flexible packages and coupled containers. In relation to different methods of transformation, nine possibilities are available today [16, 18]:

a. Extrusion.

b. Extrusion blow moulding.

c. Stretch blow moulding.

d. Injection blow moulding.

e. Injection moulding.

f. Calendering.

g. Moulding (for expanded polystyrene only).

h. Rotational moulding (rotomoulding, rotocasting).

i. Thermoforming.
In fact, PET has other interesting applications: wide-mouth jars and tubes, trays, coatings, and so on [18]. With reference to thin and biaxially oriented PET films, the best applications are retort packaging, dual ovenable lidding and ‘boil in the bag’ products [18].

Every process may theoretically generate HACCP risks with hygienic and/or aesthetical implications. The situations mentioned below, identified with the acronym PFnn (Section 2.1.12), correspond to the most well-known possibilities. All situations are correlated with the technological explanation of the involved steps.

2.2.1.1 PF12 Bubbling

This failure is normally generated when melted polymeric masses are extruded to obtain tubes, films, coatings for wires, adhesive tapes and other uninterrupted materials according to Milana and co-workers [16]. In detail, the chosen polymer (or polymeric mixture) is melted and the resulting mass is forced to pass into the so-called ‘extrusion die’ under pressure until a well-defined shape is obtained that is released after cooling. The defect is caused by the incorporation of air bubbles into melted masses and/or the generation of residual gases by heated polymers under drastic thermal conditions. Concerning bubbling, three controls are essential: viscosity of melted masses; speed of extrusion; performance of cooling systems. Bubbling may become dangerous if these air bubbles are small in size and extremely diffused. Should these conditions be verified, the uniformity of the polymeric network is not compromised on a large scale but contiguous clusters (masses composed of a few polymers) may be chemically disjoined by incorporated gases. Consequently, mechanical damage (fractures, invisible abrasions) can occur.

In addition, low thickness values may easily cause the rupture of air bubbles. Finally, it has to be remembered that delayed oxidative reactions (causes: residual gases, incorrect storage, UV rays, heating) may deteriorate plastic containers with the emergence of opalescent zones.

2.2.1.2 PF13 Aesthetical Defects

These failures can be discussed together because of the nature of the damage suffered. Related causes are generally the erroneous or insufficient control of process parameters: applied pressure on melted masses, melting and cooling temperatures. The obtained containers seem to be variable in relation to transparency and show large opaque zones without air bubbles. The above-mentioned defects are dependent on notable thermal variations during the extrusive process. As a result, viscosity values
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are not constant and resulting materials show microscopic vacancies and undesired polymeric agglomerations (crystallites and separated accumulations) with consequent fragility and delayed fractures [19, 20]. One of the most well-known examples is the behaviour of certain thermosealable plastic boxes that suffer macroscopic ruptures in the hot-sealing step. Aesthetic defects are already anticipated in PF11 (bubbling).

2.2.1.3 PF14 Extrusion Failures

This category contains all defects that can be caused by incorrect extrusion with the exclusion of PF12 and PF13 situations. In fact, these failures should be discussed in relation to mono-oriented and bi-oriented films. However, implications are related to a variety of packages, including PET bottles. Generally, all thin films are produced [16] by pressing melted masses through a linear fissure (dimension: 0.05 mm) with the exception of bi-oriented materials that have been subjected to stretching in two directions. As a result, undesired lines may be observed on resulting sheets because of the presence of foreign bodies adherent to the fissure and consequent marking. These lines correspond to long or short scratches on plastic surfaces with negative effects on the integrity and firmness of containers and related barrier effects. Additionally, mono-axially stretched sheets cannot be subjected to further tensions on these points.

On the other side, biaxially oriented films are stretched in two different and perpendicular directions by means of opposed rollers and related jaws. The polymers used (polypropylene, polyamides, polyethylene terephthalate) have to be extruded and processed with careful attention to excessive heating and correct viscosities. Because of the crystalline and linear nature of these polymers (Section 3.1), extruded materials have to remain exposed at certain thermal values. As a result, polymeric chains are allowed to maintain the bidimensional orientation (and consequent flexibility and resistance features) without the return to thermodynamically favoured amorphous structures.

In relation to these processes, two different failures can be shown. Firstly, the sheets and containers obtained may lose their uniformity because of erroneous thermal control (heating and/or cooling). These are different from PF12 and PF13 defects, the problem is essentially the inconstant flexibility of the materials obtained in relation to one direction. As an example, bi-oriented sheets can be extremely resistant to stretching on the x-axis and suffer sudden fractures on the y-axis at the same time.

A second failure is at first sight, the apparent incorporation of foreign bodies. Generally, these ‘impurities’ seem be similar to the rest of the surface in relation to their colour. In effect, the simplest solution is the presence of amorphous polymeric agglomerations in different zones (incorrect temperature and viscosity values).
In relation to PET bottles, the extrusion process does not imply the so-called orientation. However, bottle walls are subjected to numerous tensions in different places and with various orientations. As a result, all defects related to fragility can be discussed in a very similar way.

### 2.2.1.4 PF15 Coupling Failures

This category of defects is related to all materials that can be coated with extruded plastic films (PF14). These objects are called ‘coupled packages’ ([Section 2.2.2](#)). From the technological viewpoint, coupling is conducted well if plastic films are completely adherent to the supports (aluminium, paper, and so on) and an acceptable uniformity is assured. However, the adhesion is dependent on melting and cooling temperatures. Consequently, improper processing may cause imperfections such as the presence of inner creases, lack of adhesion with air incorporation and bubbling (if viscosity values are altered). As a result, the impermeability of coupled films is seriously compromised. In addition, every active substance with some important feature for food products ([smoke flavourings, Section 6.2](#)) may be imperfectly deposited on similar materials.

### 2.2.1.5 PF16 Coextrusion Failures

In reference to polycoupled packages – composed of various polymers, paper, thin pasteboard, aluminium foils – separate extrusions can be produced together: up to seven different subprocesses. Moreover, each extruded material – including printed sheets – can be provided with an adhesive layer so that the lamination and coupling steps may be achieved simultaneously. The same thing can be obtained when corrugated cardboard is produced ([Section 2.3](#)). Related failures are: microscratches, different flexibility of separated materials and consequent wrinkles into multilayered packages, insufficient adhesion between different layers because of incorrect adhesion. [Section 2.3](#) (paper and paper-based packages) describes these defects in detail.

### 2.2.1.6 PF17 Failures Related to the Stretch Blow Extrusion Step

This process is necessary to obtain PET bottles and similar packages by a preformed tube (parison). The parison is heated to fixed temperatures by means of infrared heaters. The procedure allows expansion of the parison into a two-piece mould. Finally, the container obtained is removed after cooling and mould opening. Parison preforms were previously made by the injection moulding process. In reference to these processes, related failures are similar to the previously mentioned imperfection (PF16) with the exclusion of adhesive problems. However, it remains a peculiar
defect caused by possible encrustations on mould surfaces. Consequently, different and repeated superficial damage may be shown in the same position because of the impression of encrustations on plastic containers. Additionally, the so-called ‘opacity’ of PET bottles (PF12) may have different and concomitant causes. One of these factors may be the reduction of extrusion-blow times with consequent delayed and semi-amorphous polymerisation.

### 2.2.1.7 PF18 Injection, Moulding and Thermoforming Defects

These failures are caused in the so-called ‘injection’ and ‘thermoforming’ steps. These procedures are the most well-known plastic production processes. The first method is carried out with the aim of obtaining different shapes and containers by the injection of melted polymers under pressure into a tube that contains an Archimedean screw (a tight-fitting, broad-threaded screw). The end of the tube is joined to a mould. The second process is mainly carried out in the following way:

1. Introduction of extruded plastic foils into dedicated moulds.
2. Vacuum aspiration of foils (alternative choice: foils may be stretched under vacuum).
3. Heating by hot air or infrared heaters.
4. Obtaining the desired container.
5. Removal of the package from the mould.

This procedure is economically sustainable if (1) large packages have to be produced on a reduced scale or (2) low-thickness containers have to be obtained on a large scale. In addition, the cost of necessary moulds is reduced enough in comparison to the injection process. All procedures can be carried out to produce the same package. As a result, the management of production costs is the main factor. Process times are important because thermoforming may require a few seconds to produce polystyrene/polyethylene packages with a thickness of 400 mm or several minutes to produce acrylonitrile butadiene styrene packages with a thickness of 3 mm – and the subsequent cooling step is obtained by air flow or water shower. As a result, thermoforming is slower than injection moulding. In terms of related failures, moisture incorporation has to be taken into account because moulded masses contain polymers and other substances (Section 3.1.2) including mineral fillers. These molecules are known to be hygroscopic enough to determine water incorporation, amorphous agglomeration (insertion of different phases into plastic networks) and microbubbling. Other failures are caused by unclean and/or untrimmed moulds (superficial defects, PF17).
Exclusively to the injection moulding process, the importance of the defect known as ‘dripping’ (Figure 2.21) has to be highlighted.

This imperfection, generally visible on the inner and outer sides of plastic cups (same position), may be caused by temporary variations of viscosity values when moulds are filled. This situation can depend on other factors (incorrect cooling, excessive heating of plastic materials). For these reasons, this failure – also known as ‘warping’ or ‘twisting’ – is observed in different situations [21, 22].

The rheological properties of fluid masses may determine other situations:

a. Stripes.
b. Marked images by encrustations on moulds.
c. Uncontrolled and randomised bursting of microbubbles.
d. Incorporation of foreign bodies.
e. Other microfractures caused by chemical modifications of polymeric chains.

The main problem is not the variation of viscosity values – except for sudden deviations – but the process management, since all moulding procedures are discontinuous productions and subject to possible delays.
Other known failures are:

1. Blistering [23]: certain surface areas seem raised in respect of the whole product. Causes: excessive heating of plastic materials and/or defective cooling.

2. Flash contamination: thin products (plastic dishes, and so on) seem to show fragmented but joined extensions out of their normal dimensions. Undesired plastic extensions are essentially fragile and may easily contaminate foods. Causes: moulds may be defective (erroneous closing) or be excessively filled (rheological problems).


2.2.1.8 PF19 Defects Related to the Calendering Step

This process is carried out with the aim to obtain smooth PVC foils – thickness: 200 mm – by compression between opposite cooling rollers. Related failures are substantially superficial imperfections of produced sheets. Aluminium laminated foils and flexible packages show very similar defects (see Sections 2.1.8 and 2.3).

2.2.1.9 PF20 Inner Superficial Defects by Rotational Moulding

The recalled step allows different containers to be produced by high-speed rotation of melted polymeric masses (usually polyethylene) into a mould. The packages obtained are very smooth but several rough imperfections may be present in the polymeric network because of insufficient thermal control (over-fusion temperature) or incorrect rotation speed. Additionally, some variation in superficial colours can be shown when mineral fillers and/or powdered dyes are incorrectly mixed into the resulting master batch.

2.2.2 Flexible Packages and Coupled Containers: Technology, Production and Failures

These containers have several similarities with analogous paper-based packages. Because of their plastic nature, flexible FPM can be obtained by coupling different films. Additionally, several types may be assembled at the same time as the final food packing step. Another successful strategy is the MAP technology.
On the other hand, high speed values may not be in full accordance with food safety and QC procedures in the process. In other words, the quantity ‘process time/number of steps’ is a fundamental parameter and should be carefully monitored [24]. Excessive values for this number may mean operative difficulties concerning the detection and consequent elimination/conversion of discards. As a result, imperfect or damaged packages might pass QC tests with acceptable results and good examples might be eliminated without defects according to Parisi and co-workers [25].

The manufacturing of flexible packages is multiform. The extreme variability depends on different raw materials (paper, aluminium foils, plastic films, regenerated cellulose acetate, and so on). The following list of procedures should be considered in accordance with chemical and technological features of these materials. Consequently, the reader is invited to consult Chapter 3 after this discussion.

A premise has to be made with regard to a series of containers that cannot be grouped under the name ‘flexible packages’ [16]:

a. Extensible and thermo-retractable films that are destined to seal cartons and pallets.

b. Shopping bags.

c. Self-service bags (also called temporary packages) that are destined to preserve fruits and vegetables.

d. Bags for household use only.

e. Aluminium coils and foils destined for household use only.

f. ‘Boil-in-the-bag’ packages and similar containers.

With the exception of the containers mentioned above, the manufacturing of flexible packages can be summarised by:

1. Reception, QC tests and storage of raw materials.

2. Printing process: rotogravure or flexographic methods.

3. Coupling step.


5. Packaging of containers.

6. Storage and delivery to final customers.
A number of different types can be described in relation to flexible packages, including coupled films. This list may be summarised as follows without further explanation about their basic features because of the complexity of this argument:


b. Form-fill-seal types: main feature: assembly at the same time as the final food packing step. These containers are subdivided into ‘pillow-pouch lap seal’, ‘three-side seal pouch’, ‘four-side seal pouch’ packages and other types.

c. Stand-up pouches: these packages are similar to FFS types.

Coupled containers have represented a revolutionary turning point in the food and beverage market. These materials are the logical and natural evolution of simple coupled packages. There are three reasons for this success:

a. Polycoupled packages are particularly indicated for perishable beverages (cow’s milk is the most well-known example) because of the virtual sterility.

b. Chemical and technological features allow these containers to preserve different foods under drastic thermal conditions (temperatures ≤ −18 °C).

c. Polycoupled containers can be assembled, filled and packed at the same time. This strategy may determine the possibility for shelf-life increases. On the other hand, FO are requested to assume new responsibilities.

d. Thermal preservation can be enhanced if polycoupled packages are employed.

e. Finally, the management of discarded products may be economically favourable.

At first glance, polycoupled packages correspond to a multilayered structure (Figure 2.22).
Categories and Subclasses of Packaging Materials

Figure 2.22 Polycoupled containers. A multilayered structure

This structure can be summarised as follows:

a. Firstly, an LDPE layer (packaged foods have to be protected from occasional contact with printing inks on the other side).

b. A second cardboard layer.

c. A third layer, generally LDPE.

d. A copolymeric film such as the ionomeric poly(ethylene-co-methacrylic acid) zinc salt.

e. A final LDPE protective layer.

The distribution and related thicknesses can be extremely variable. For beverages and meat-based products, the preferred sequence is: paper (in contact with packaged food)/polyethylene/aluminium and polyamide/ethylene vinyl acetate.

Polycoupled systems have to be designed on these bases:

1. The prediction of the so-called ‘barrier effect’ (Section 3.1.1).

2. The compatibility between various polymeric layers.

3. The conformity to migration tests.
4. Possible legal restrictions about certain raw materials and intermediates: bisphenol-A diglycidyl ether, bisphenol-F diglycidyl ether, Novolac glycidyl ethers, and so on. In relation to recent problems, the most well-known example is related to BPA and its presence in a number of plastic and ‘hybrid’ containers (Section 5.2.4). The position of metal can producers on BPA is unclear and being debated [26].

In reference to flexible and polycoupled containers, Table 2.2 shows current applications.

| Table 2.2 Poly-coupled packages. Main typologies and related applications |
|-----------------------------|---------------------------------|
| **Food packaging category** | **Food and beverage applications** |
| **Macro-category: coupled cardboard films** | |
| By separated spools | Fluid applications |
| | Suitable for solid and slightly fluid products |
| Preformed films | Fluid applications |
| **Macro-category: bags** | |
| Pillow-pouch fin (lap) seal types | All applications |
| Three-side seal pouches | Fluid and pulverised foods |
| Four-side seal pouches | Fluid and pulverised foods |
| Stand-up pouches | Fluid and solid foods |
| **Macro-category: coupled boxes and trays (all applications)** | |
| All types obtained with patinated paper, cardboard, and so on | Household and industrial applications, including catering services |
| **Macro-category: punched containers** | |
| All types | Refined vegetable products (rice, and so on), pastry products, baked foods |

In relation to the objectives of this book, the best strategy should be the description of one polycoupled packaging on condition that this container can summarise all positive and negative features of the entire group of materials. Tetrahedral packages (Figure 2.23) have shown excellent results in relation to juices (orange, grapefruit, tomato, and so on), wines and conditioned cow’s milk (sterilised, pasteurised).
It has to be recognised that:

1. These containers are assembled and thermosealed by FO. In other words, the original spool is welded (Section 3.1) on previously determined zones by means of spiralled resistances.

2. The top and bottom closures (Figure 2.22) are equally thermosealed. Consequently, tetrahedral containers are not considered in the same way as similar cartons or boxes. It can be affirmed that these packages do not have different ‘up’ and ‘down’ sides in relation to possible microbial contamination and hot-sealing failures.

3. Tetrahedral packages can be provided with different caps on the ‘top’ side by means of precut openings before hot-sealing and packing operations.

On the other side, three disadvantages have to be highlighted and discussed (Figure 2.22) with possible countermeasures:
1. Thermosealed closures correspond to the main technological risk of tetrahedral packages and other polycoupled categories since all closing operations are carried out by the food industry. Food operators have to be trained in this procedure and related risks (QC tests on FPM, and so on).

2. Polycoupling techniques allow extremely rapid sanitisation procedures (sterilisation, and so on). Should these operations be slower than expected, all production steps would suffer notable delays. From the technological viewpoint [24, 27], products obtained might have reduced shelf-life values compared to ‘traditional’ systems (glass bottles, and so on) according to Parisi and co-workers. This aspect has to be carefully examined when different packaging strategies are compared.

3. Residual fractions of food materials may be dispersed and blocked into the thermosealed closure. As a result, the following defects may be observed: bad thermosealing, microholes (sealed interstices), anomalous fermentations (oxygen is absent or very reduced) with unpleasant smells and possible hygiene problems (Section 8.5).

In relation to the first two points, the management of risks is strictly dependent on the topology of FPM. The problem of food residues in the interstitial sealing has been managed with the creation of alternative coupled containers that are preformed by single flattened pieces. These packages are sealed by PO only, with the exception of one necessary opening. In other words, new, evolutionary systems are similar to ‘old-type’ containers such as cardboard boxes.

In recent years, two important innovations have been designed and implemented concerning polycoupled packages:

1. New low weight packages have been introduced for liquid applications. These containers are produced with the following layer sequence: white LDPE (inner side)/brown LDPE/polyamide/brown LDPE/white polypropylene (external side). This solution is considerably lighter (25 g) than other similar containers.

2. Tetrahedral containers have been made suitable for different foods without complicated constraints (peas in sweetened water, dried spices, peanuts, and so on).

Concerning HACCP risks, the most relevant problems are shown here. It has to be remembered that flexible packages may show other failures in the same way as plastic and paper materials. Consequently, previous PF defects always have to be taken into account.
2.2.2.1 PF21 Printing Failures Related to Rotogravure and Flexographic Steps, including Bleeding

Concerning flexible packages, the application of printing inks is made by direct contact in two ways. In the rotogravure process, all pigments can be impressed at the same time (up to 10 or 11 inks) on the spooled film [16]. Every printing roller – one per ink – draws the right quantity of pigment from a basin with the aim of wetting exclusively engraved zones that constitute the final picture.

All inks are clearly diluted with a selected solvent, usually ethyl acetate, because the rheological properties of pigments have to remain constant during the production (see PF03). It has to be anticipated that printing inks are a mixture of different materials including mineral or synthetic pigments (responsible for the desired colour) and various polymers (responsible for the incorporation of pigments into solid plastic networks). After the rotogravure process, excess inks on engraved zones can be removed by a knife and consequently returned to the original basin by simple percolation. Finally, printed packages have to be dried (stripping step) in dedicated ovens.

Flexographic systems are not similar to rotogravure but related defects are similar. For this reason, the flexographic procedure will be described later (Section 2.3, PF26).

Most printing failures can be easily observed because of their macroscopic dimensions. Generally, these defects are caused by an incorrect application of inks on the support with superposition of different pigments. Paper and paper-based packages often show similar rough imperfections (see Sections 2.3 and PF26). However, printing failures may have other origins. Firstly, the mass of defects caused by improper control of ink viscosity has to be highlighted. Rheological properties of ink solutions may suddenly mutate if environmental conditions are severe (high temperatures and excessive ventilation) because of the rapid evaporation of ethyl acetate. Should viscosity increase constantly and rapidly, the following events should be observed and monitored:

1. Prepolymerisation of inks in the basin before transfer on printing rollers.
2. Amorphous agglomeration of inks (formation of prepolymerised particles, accumulation of mineral fillers and/or pigments) in the basin before transfer onto printing rollers.
3. Coprecipitation of pigments and polymers (Section 3.1.4) in the basin before transfer on printing rollers.

On this basis, it can be inferred that the impressed inks may be incongruous and partially powdered. As a result, the adhesion to plastic supports can be insufficient with possible removal from printed surfaces and the tendency to create emulsions with residual water particles if relative humidity is moderate. This event determines a
sort of ‘trespassing’ (removal and transfer) of printing pigments from assigned zones or borders. With relation to this specific phenomenon, the name ‘bleeding’ seems appropriate enough (Figure 2.16). In addition, all inconsistent and removable inks can easily be transferred onto other supports by simple contact (see PF03 and the so-called ghosting effect). It has to be anticipated (Section 3.1.4) that several pigments are hygroscopic enough to absorb water particles and this possibility can worsen the final appearance of printed images.

From the HACCP viewpoint, bleeding failure and related defects can be dangerous because incongruous and/or partially dried inks are subjected to easy removal and transfer onto other materials, including foods. The following steps have to be monitored:

1. The normal manipulation of FPM (FO are clearly unaware of the previously mentioned risks); and/or
2. Casual removal of inks from packaging lines (cutters, knives, and so on) because of initial friction and consequent contamination.

2.2.2.2 PF22 Coupling Failures

These defects are casual creases that can be present after the adhesive coupling between the printed film and one (or more) thin supports (plastic nature). In relation to multilayered packages, the intermediate layer is an aluminium foil. It should be considered that \( n \)-layer packages contain \( n - 1 \) additional layers with the following features: (1) discontinuous nature and (2) reduced thickness. These zones consist of polymer-based adhesives – dissolved or solventless glues – that are necessary to complete and improve the process [16]. The application of these adhesives has to be carried out by means of dedicated rollers on plastic supports. Adhesive layers have to be dried for two reasons: evaporation of ethyl acetate or other organic solvents (dissolved glues) and initiation of polymerisation processes.

Once more, viscosity and environmental conditions (storage and process temperatures should not be too high or low) have to be carefully monitored and managed to obtain good results. Otherwise, applied adhesives may appear incongruous. In detail, excessive viscosity values cause (1) discontinuity in the drawing of adhesives and subsequent application on roller surfaces and (2) potential amorphous agglomeration because of apparent thixotropy (see PF03). Low temperature values (improper storage conditions) can worsen the entity of adhesive failures.

Alternatively, prepolymerisation can occur (PF03) with consequent agglomeration on the bottom of original storage drums if the application is conducted when temperatures
are > 25 °C. The final result is the emergence of macroscopic defects such as creases and the incorporation of foreign bodies into flexible films. This is the interpretation of FO. The presence of inner creases and other imperfections is generally observed with increasing permeability: the barrier effect is not assured. In addition, coupling defects can compromise thermowelding procedures with potential increases in discarded packages and the consequent rise of production costs (process stoppages). It has to be considered that coupling failures may be manageable and reducible if obtained packages are stored in heated warehouses where relative humidity and temperature values are constantly monitored, but the complete elimination is impossible.

2.3 Paper and Paper-based Packages

These materials are destined for a variety of different food applications, which are similar to plastic containers (Table 2.3).

| Table 2.3 Paper and paper-based packages. Main typologies and related applications |
|---------------------------------|---------------------------------|
| **Food packaging category**     | **Food and beverage applications** |
| Macro-category: paper for food preservation |  |
| Cellulose-based papers           | Catering applications           |
| Greaseproof papers               | Catering applications except for moist foods |
| Pergamin papers                  | Catering applications           |
| Impermeable papers               | Catering applications           |
| Moisture- resistant papers       | Household use and catering applications, including take-away foods |
| Powered films                    | These films are destined to further transformation and production of coupled packages (Section 2.2.2) |
| Macro-category: corrugated cardboard | Secondary packages              |
| Macro-category: thin pasteboard  | Cups and other secondary packages |
| Macro-category: patinated pasteboard | These papers are destined to further transformation and production of coupled packages (Section 2.2.2) |
| Macro-category: regenerated cellulose | Domestic and catering applications. This material can be coupled with other materials (Section 2.2.2) |
2.3.1 Technology, Production and Failures of Paper and Paper-based Packages

From the technological viewpoint, the production of papers and paper-based packages can be summarised as follows [16, 28]:

1. Arrival, QC tests and storage of raw materials (Section 3.2).
2. Preliminary operations: mechanical pulping, chipping, chemical pulping.
3. De-inking (this step is required when recycled papers are used).
4. Spool processing, partial squeezing under pressure and final drying.
5. Size press or superficial coating (this step can be required for printing processes).
6. Patinating (this step is necessary for patinated papers).
7. Finishing (superficial treatments).
8. Transformation of the spool obtained into final products: paper packaging, corrugated board or folding box board (also called cartonboard).

The final transformation procedures are subdivided into different substeps. The following list may be helpful as an example (corrugated cardboard):

a. Arrival, QC tests and storage of spools.

b. Corrugating and coupling.

c. Roto-off-set or flexographic printing process.

d. Punching and creasing (also called folding).

e. Automatic, manual or ‘hybrid’ composition.

f. Packaging, storage and distribution.

In reference to paper packaging (bags), the production steps are discussed in Section 2.2.2 (flexible packages). In fact, these containers are obtained by coupling (raw materials: paper spools and plastic films).

From the HACCP viewpoint, the most well-known and repeated failures are discussed here.
2.3.1.1 **PF23 Excessive Rigidity of Materials**

This imperfection is caused by an erroneous combination and mixture of glues in the second step (preliminary operations). In fact, initial mixtures are composed [16] of mineral fillers, dyes, sizing agents, wet strengthener resins, defoamers, biocides and adhesive products with the aim of obtaining paper sheets with predictable and acceptable rigidity. It has to be considered that paper-based materials are more or less resistant to mechanical tensions depending on the presence of mineral fillers and adhesives. Consequently, every error in the management of this step (low presence of glues, reduced speed of rotation, and so on) may cause damage and potential lacerations to obtained sheets or spools before the cutting step.

Other causes are high quantities of fillers that are usually added with the aim of whitening paper sheets. However, it should be specified that cellulosic fibrils may show some chemical incompatibility with minerals. In addition, the presence of organic dyes and albumins may produce other disadvantages since these substances are chemically similar to cellulose with the exclusion of inorganic fillers. In the successive ‘side press’ or coating step (this passage is optional), the addition of adhesives is judged necessary to obtain good rigidity and mechanical resistances. On the other hand, the control of uniformity is essential to guarantee good or acceptable results.

2.3.1.2 **PF24 Colorimetric Variations**

Several claims are related to the appearance of different tints on the same paper sheet. Generally, the main causes have to be searched for in the initial preparation of cellulosic mixtures with reference to the introduction of albumins that tend to turn yellow because of ‘ageing’ (the sum of chemical reactions catalysed by UV rays and high storage temperatures). Moreover, the removal of old inks in recycled papers is carried out with the addition of bleaching agents (oxidant substances). These agents are able to modify the appearance of final sheets with unacceptable results. It has to be considered that the ‘yellowing’ effect can be positively judged with reference to certain historical books but FO and consumers cannot be favourably predisposed. In addition, yellow tints seem to increase progressively if storage conditions (high relative humidity, sunlight exposure) are unfavourable. This failure is amplified by the overlap of different pigments in the optional ‘patinating’ step. Finally, the possible incorrect addition of so-called fluorescent whitening agents into initial mixtures has to be considered.
2.3.1.3 PF25 Paper Wrinkling

Cellulosic mixtures are transformed in a continuous tape after their preparation. Excessive viscosity and/or speed values may determine variability in the amalgamation of cellulosic fibrils and consequent differences in the paper structure along the sense of progression. As a result, various ripples may be observed locally on the final tapes. These imperfections may be very dangerous for paper tapes because of the required mechanical resistances and superficial integrity. Moreover, the worsening of modest barrier properties has to be highlighted.

In the optional patinating step, the multilayer overlapping of different pigments can increase the appearance of ripples and lacerations. Patinating performances are not guaranteed.

The failure is made worse in corrugated board boxes. Three finished paper tapes are corrugated and overlapped (total: three layers). Superior (fluting) and intermediate (middle) tapes are corrugated by means of a dedicated cylinder and superficially coated with starch glues. Finally, modified and coated tapes are overlapped and the resulting cardboard is heat-pressed on the third tape. Obviously, adhesive properties and the general stability of corrugated cardboard are worsened by local ripples and different rigidity values (see also PF23).

2.3.1.4 PF26 Bleeding (Paper Packaging, Off-set Printing)

This failure has been already discussed (PF21) without reference to off-set printing. The previously mentioned system allows printing by indirect image transfer. In other words, printing inks are dissolved in organic solvents because of their lipophilic nature and subsequently deposited on dedicated zones of a special rubber roller, while complementary areas (hydrophilic nature) are wetted by aqueous solutions without ink invasion or overlapping. The printing process is followed by the finishing coating step (off-set of flexographic options) with the aim of protecting all images from scratches and various abrasions. Intermediate products are successively dried (heating, ‘heat-set’ method, or cooling).

Despite the simplicity of off-set processes, final results may show ‘bleeding’ or ‘ink shifting’. This name (PF03 and PF21) implies the possible invasion of printing inks on hydrophilic areas (no printed images) and the consequent water/oil emulsion. Related causes are linked to surface tension values and rheological properties of dissolved inks. This failure concerns the visual appearance of printed images. Nevertheless, emulsified inks may be partially dried and remain ‘active’ under pressure with consequent removal and transfer of pigments and/or the superimposed finishing coating. One
of these collateral defects is called ghosting (PF08). Abrasions can easily occur on damaged zones. It has to be highlighted that bleeding is not shown if UV inks are used (Section 3.1.1).

2.3.1.5 PF27 Flexographic Printing and Related Failures (Paper Packaging, Corrugated Cardboard)

Flexographic printing, already introduced without discussion in PF21, allows printing by direct image transfer.

In other words, printing inks are deposited on a rotary press and directly transferred to the paper support. These substances are called water-based inks if they have to be dissolved in water or solvent-based inks if they have to be dissolved in solvents such as ethyl acetate or alcohol mixtures).

Printing is followed by the finishing coating step with the aim of protecting all images from scratches and various abrasions. Intermediate products are successively dried (stripping) in dedicated ovens.

Related failures are determined by incorrect drying, residual incorporation of water or organic molecules and consequent softening of printed papers. In addition, damage may be observed on printed and ‘neutral’ (no images) sides because of intra-sheet migration of solvents. Partially dried inks may be removed and transferred under pressure by simple contact (ghosting, PF08 and PF21). This failure may be worsened if storage conditions are not optimal (high relative humidity values; temperatures > 25 °C; evident sunlight exposure). Should these conditions be verified, the ‘solidity’ of printing inks (the capacity to maintain the original tint in adverse conditions, Section 3.1.2) would be compromised.

Other imperfections related to flexographic processes are: ink agglomeration, ink prepolymerisation, and precipitation of pigments and polymeric masses. These failures have already been described with reference to the rotogravure process (PF21).

2.3.1.6 PF28 Excessive Dripping (Corrugated Board)

Normally, corrugated cardboard is used for the production of rigid boxes. This step can be carried out in three ways:

a. Automatic process.

c. Hybrid process (in other words, an arrangement between automatic and manual options).

Final boxes are assembled with vinylic glues or ‘hot-melt’ adhesives with the aim of obtaining good mechanical resistance. However, several thread-like dispersions may be observed on the inner surface of these containers with relation to folded angles (Figure 2.24).

These filaments are not considered dangerous because corrugated board boxes are destined to contain packaged products. However, the presence of vinylic glues or other adhesives has to be discussed when the dispersions described above are observed on plain areas (Figure 2.24) and the foods to contained in them are not packaged (absence of superficial protection against adhesive contact).
2.3.1.7 PF29 Adhesion Defects (Paper Packaging)

For paper bags (coupled packages Section 2.2.2), casein-based adhesives are used extensively [29]. Different imperfections are apparently linked to these glues when plastic films and paper layers are coupled. In fact, casein-based adhesives are one of the most used strategies because of their high performance and relatively low costs. Caseins are obtained from cow’s milk (enzymic or acid coagulation). The word ‘casein’ corresponds to a vast aggregate of different dried proteins with calcium phosphates and other mineral substances. As a result, casein powders are hygroscopic substances. This property is reduced if caseins are obtained by acid coagulation and successive drying [30–32]. These powders are called ‘acid’ and ‘non-edible’ caseins. These proteins can be dissolved in alkaline solutions to obtain good glues. The abundance of peptide groups allows caseins to show strong links (hydrogen bonds, other chemical connections) with cellulosic groups (paper supports) and water molecules (residual moisture). The balancing between first and second interactions gives strong adhesions if paper supports are preferentially linked to peptide groups. On the other hand, bad results may be shown if the atmospheric moisture blocks the majority of peptide groups (hydrogen bonds) with consequent poor linkage to cellulose residues. It has to be noted that these situations are extremes of a vast range of possibilities. In relation to adhesion failures, reduced performances (excessive moisture, high relative humidity) are observed with possible pulverisation (partial decomposition, PF30) of joined papers. Excessive dripping (PF28) may be observed and consequent damage is possible if joined bags are filled and successively stored on pallets within humid areas (moisture-sensitive adhesives are not permanently blocked and may show residual activity). Other adhesives may show similar behaviours.

2.3.1.8 PF30 Paper Pulverisation (All Paper Packages)

This failure is observed in multilayered packages if intermediate paper materials are stored or processed into humid areas. Consequently, cellulosic groups and other components (mineral fillers, and so on) tend to adsorb residual moisture in the same way as casein-based and water-based glues (PF29). General pulverisation is similar to mildewing (PF31) but decomposed materials do not show green or brown mycelia.

2.3.1.9 PF31 Paper Mildewing (All Paper Packages)

This well-known failure can be effectively contrasted by anti-mould agents or special coatings. Mildewing is similar to pulverisation but decomposed materials show clear signs of infestation (green or brown mycelia) by moulds. These eukaryotic organisms can produce branched filamentous hyphae in adequate conditions (high moisture,
darkness) with notable speed. Clearly, the infestation by moulds may be observed by FO in chilled rooms as for yeasts, according to Parisi [33–35]. This is the most evident example of passive microbial contamination concerning food packaging (Chapter 9).

2.4 Glass-based Packages and Ceramic Containers

Glass containers are extensively used in relation to food and beverages. However, their use is circumscribed and linked to particular food products. The same thing can be observed in relation to ceramic packages (Table 2.4).

<p>| Table 2.4 Glass- and ceramic-based packages. Main typologies and related applications |
|---------------------------------|---------------------------------|</p>
<table>
<thead>
<tr>
<th>Food packaging category</th>
<th>Food and beverage applications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Macrocategory: glass containers</strong></td>
<td></td>
</tr>
<tr>
<td>Bottles with narrow neck, no handles. These containers can be plugged, corked, or capped</td>
<td>Water, wines, soft drinks, beer, and so on</td>
</tr>
<tr>
<td>Food-contact carboys with handles</td>
<td>Vegetable oils, luxury wines, and so on</td>
</tr>
<tr>
<td>Glass jars</td>
<td>Preserved foods, canneries, dried products (coffee powder, peanuts, and so on), fish products</td>
</tr>
<tr>
<td><strong>Macrocategory: ceramic containers</strong></td>
<td></td>
</tr>
<tr>
<td>Decorative pots</td>
<td>Luxury foods and regional recipes</td>
</tr>
</tbody>
</table>

2.4.1 Glass-based Packages and Ceramic Containers. Technology, Productions and Failures

In spite of different processes – blow and blow or press and blow techniques – and final containers, the manufacturing of glass packages can be easily summarised in the following way, according to Milana and co-workers [16]:

a. Checking, QC tests and storage of raw materials.
b. Dosing and preparation of glass mixtures (mixing).

c. Access to fusion furnaces.

d. Furnace operations (melting and refining).

e. Thermal conditioning, with the aim of obtaining molten glass masses with excellent ductility.

f. Cutting of molten glass streams and forming procedures.

g. Internal treatment (for alcoholic beverages).

h. Glass annealing (gradient cooling).

i. QC tests.

j. Packaging and/or palletising.

k. Storage and delivery to FO.

The first stages (a–g) are absolutely critical. Consequently, the reader should understand the different and complicated explanations about glass chemistry. Concerning this point, the author has decided to mention only basic concepts in Section 3.3. On the contrary, complex arguments have been mentioned in this section if some connection with potential failures can be established.

Concerning glass containers, HACCP risks are listed in the next sections.

2.4.1.1 PF32 Microbubbling

The success of fusion processes depends on the so-called ‘refining’ step. This stage corresponds to the prolonging of melting procedures (temperatures: 1,450–1,550 °C) and the objective is the total elimination of air bubbles in glass matrices. These gaseous incorporations can compromise the intrinsic stability because glass matrices are forced to exhibit crystalline-like behaviours with the tendency to form thermodynamically favoured amorphous structures (Section 3.3). As a result, all macroscopic vacancies and gaseous holes must be eliminated where possible. Otherwise, glass containers can suffer possible fractures where microbubbles are present. In relation to refining performances, normal glass materials contain different metals (aluminium, boron, phosphorus, and so on) in various proportions (Section 3.3). In addition, small fractions of the total volume are ‘empty spaces’ and their presence is inevitable.
2.4.1.2 PF33 Visible and Invisible Microfractures in Glass Structures

At first glance, these defects are similar to microbubbling (PF32). However, it has to be highlighted that the occurrence of more or less evident fractures does not only depend on gaseous vacancies. In fact, molten glass masses cannot be immediately shaped after the necessary refining. This step is described in the following PF34 subsection. Intermediate materials have to be progressively cooled and process times are long enough to allow acceptable viscous masses to be obtained. In relation to this ‘gradient’ cooling, temperatures have to remain between 1,000 °C and 1,350 °C. All parts of the vitrified fluid should reach and maintain the same thermal values without appreciable discontinuity. This affirmation implies that all sections of molten glass fluids are in thermal equilibrium. Intermediate materials should be imagined as a continuous and fluid cylinder, which might be subdivided into ‘n’ cylindrical subsections or ‘plates’ along the longitudinal axis or ‘directrix’. Moreover, the chemical composition of the imagined cylinder is constant along the directrix because equal thermal values mean equal probable structures on a microscopic scale.

Different thermal values in the same fluid can imply a certain discontinuity of chemical compositions, plate by plate. In other words, the higher the difference between temperatures and their decrease, the higher the probability of ‘n’ possible chemical structures (melted phases). Consequently, the risk of microfractures is always high between the nth and the nth + 1 phases. This failure is really dangerous at the end of the ‘shaping’ step (PF34) because of possible ruptures and hidden microbubbles caused by a sudden decrease in temperature.

2.4.1.3 PF34 Scratches Related to Forming and Glass Annealing Steps

These imperfections are generally concomitant with forming (shaping) and successive cooling steps. The first of these passages is introduced by the ‘cutting of molten glass streams’ process. In other words, a certain fraction (gob) is cut away from semi-fused masses and successively shaped by blowing air into it through a tube (blow and blow technique). This ‘shaping’ procedure is carried out with the aim of obtaining traditional bottles [16]. On the other hand, large mouth-jars and similar containers can be produced by pressing preformed parisons into metallic moulds (press and blow technique). These procedures are largely employed to produce glass packages for food applications.

Intermediate containers are superficially coated (refining step) with the aim of improving glass resistances against sudden thermal variations and/or impacts. These techniques are carried out:
Categories and Subclasses of Packaging Materials

a. At the end of the shaping (hot-end coating, 500 °C); or
b. After a successive cooking; or
c. After the final cooling (cold-end coating).

In relation to the forming (shaping) and refining steps, three different failures may be observed on glass surfaces (inner and outer sides) and in these materials. Two of these defects have been partially discussed.

Firstly, the materials obtained may show microscopic failures (lack of uniformity) with consequent microfractures (PF33). It has to be noted that this damage might be caused by too rapid cooling, heterogeneous composition (preparation of mixtures) or superficial damage on the moulds used. The final results are microbubbles (PF32), microfractures (PF33) or dripping damage. In reference to the last possibility, superficial defects are similar to failures described for plastic packages (PF18).

Secondly, mechanical resistances may be reduced (PF33) in the absence of visible signs. This defect may be originated in two distinct ways – thermal conditioning and superficial coating (after gradient cooling) – so that the attribution may be difficult.

Finally, superficial scratches and macroruptures may be observed. These abrasions are generally caused in the superficial coating step if they are clearly visible on the external surface. The reason has to be searched for in this step because superficial coating is carried out with the aim of reducing friction coefficients of glass surfaces when these are obliged to move on bottling lines. Consequently, scratches should not be observed if coating procedures have been carried out with acceptable performances.

2.4.1.4 PF35 Other Failures Related to Glass Stability: Macrofractures, Superficial Abrasions, Colorimetric Variations

Once more, these defects – visible fractures or colours – may be ascribed to different steps. At first glance, stability can be compromised in the following ways: refining (PF32); thermal conditioning (PF33); glass annealing (gradient cooling, PF34). In reference to the last passage, shaped materials are heated at 550 °C and successively cooled to 25 °C. The total duration is extremely long because of the necessity to avoid sudden thermal variations and consequent tensions to glass matrices (PF32). This process is comparable to the so-called tempering step that is employed to produce resistant metallic laminates (Section 3.3).

Sudden fractures, superficial abrasions and colorimetric variations are ascribed to glass annealing if:
1. Materials obtained are produced with exceptional resistances (unbreakable packages); and/or
2. Initial formulations contain particular compounds with the aim of increasing mechanical features (Section 3.3).

Concerning possible mistakes about the chemical formulation, local colorimetric variations may be caused by incorrect mixture of components (mixing step: Section 8.4) and/or rheological problems (Section 3.3).

2.4.1.5 PF36 Sharp Edges and Other Removable Materials

This group of failures should be considered and managed by the QC team of PO (and FO). The previously mentioned defects originate in the following steps: superficial coating (shaping, PF34) and/or glass annealing.

2.4.1.6 PF37 Possible Scraps and Shivers into Final Containers

Once more, statistically it is not possible to eliminate this problem and it should be correctly managed by the QC services of PO and FO.

2.4.1.7 PF38 Cleanliness and Mechanical Resistance (Reusable Glass Containers)

In reference to hygiene problems, all used containers (bottles, jars, and so on) are washed with caustic solutions and carefully dried. Reused glass containers may be partially damaged on inner and outer surfaces because of:

1. Inevitable and protracted contact with strong or slightly acid foods before reuse.
2. Superficial contact with caustic substances and possible removal of peripheral layers from damaged surfaces on both sides.

Because of the unstable behaviour of glass materials (silicone-base networks with other metals and anions), caustic washing has to be carried out with careful attention. If this does not happen, the following problems cannot be avoided:

a. Accelerated ‘ageing’ and consequent risk of inner fractures because of the return to silica-like amorphous structures instead of preferred glassy networks.

b. Enhanced shocks after sudden thermal variations.
c. Migration of metallic ions and other substances towards the contained foods.
d. Opacity, removal of scraps, and so on.

As a result, FO are requested to check the ‘technological suitability’ (Section 4.1) of reusable glass containers before packing procedures (QC tests).

Moreover, the previously mentioned damage can occur with increasing probability depending on the number of caustic washes. Other defects (stratification of calcium carbonate, and so on) may be possible.

**2.5 Smart Packages**

This section is dedicated to the newest class of devices that can be applied to foods and beverages. A premise should be made about these packaging objects because of the incorrect classification [36]. With reference to smart devices, one of the main functions related to packaging materials – the protection of contained foods from external agents – is not applicable.

Smart packaging is a qualifying accessory for food products and related containers. Moreover, this material is explicitly conceived to satisfy different purposes in comparison to normal packages. In detail, smart materials are required to interact with packaged products [37]. This interaction is possible if smart objects are connected to ‘main’ and traditional packages so that the final food product may be synergically represented in this way: food/main packaging/smart packaging.

On the other hand, the adjective ‘smart’ is not sufficiently clear concerning the explicit function of these materials.

Smart packages can be considered to be a separate group of devices compared to traditional food accessories. This definition has to be completed with a further subdivision between ‘active’ and ‘intelligent’ packages (Figure 2.25).
The active packaging is able to interact with the inner atmosphere or the package.

The intelligent packaging is designed to communicate particular information about the story of packaged products without active interaction.

**Figure 2.25** The world of smart packaging. Active and intelligent devices

These materials are different enough to justify separate arguments. Concerning the second group, the discussion has been postponed (Section 2.7). The so-called ‘active’ packaging is discussed here.

The interaction of ‘accessory’ devices with preserved foods can be active or passive. The first behaviour is expressed by active packages with the continuous modification (by means of antimicrobial and/or antioxidant substances) of the inner atmosphere in a predetermined direction. Active modifications can improve shelf-life values and sensorial features of packaged foods (texture, perceived smell, general appearance, and so on).

This is the main difference between active and intelligent devices: the latter are required to record different information without modification of the contained foods and atmospheres into containers [37].

From the technological viewpoint, active solutions (Table 2.5) can be subdivided into four macrocategories concerning their nature and main destinations according to Delia and co-workers [38] and Day [39].
### Table 2.5 Active packaging - four macrocategories and related applications

<table>
<thead>
<tr>
<th>Food packaging category</th>
<th>Food and beverage applications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Macrocategory: gaseous scavengers</strong></td>
<td></td>
</tr>
<tr>
<td>Oxygen scavengers</td>
<td>General applications</td>
</tr>
<tr>
<td>Carbon dioxide scavengers</td>
<td>Dried and pulverised products; meat-based and vegetable foods</td>
</tr>
<tr>
<td>Moisture scavengers</td>
<td>Dried and pulverised products; meat-based and vegetable foods</td>
</tr>
<tr>
<td>Ethylene scavengers</td>
<td>Dried and pulverised products; meat-based and vegetable foods</td>
</tr>
<tr>
<td><strong>Macrocategory: gaseous emitters</strong></td>
<td></td>
</tr>
<tr>
<td>Carbon dioxide emitters</td>
<td>Vegetable products</td>
</tr>
<tr>
<td>Ethanol emitters</td>
<td>Baked products</td>
</tr>
<tr>
<td><strong>Macrocategory: preservative releasers</strong></td>
<td></td>
</tr>
<tr>
<td>Antimicrobial films (active principles: Nisin, lysozyme, Imazalil, and so on)</td>
<td>Fish products, fresh fruit</td>
</tr>
<tr>
<td>Antioxidant films (active principles: butylated hydroxytoluene, butylated hydroxyanisole, vitamin E)</td>
<td>Grain and similar products</td>
</tr>
<tr>
<td>Enzyme releasers (active principles: peroxidase, glucose oxidase, and so on)</td>
<td>General applications. Excellent results with dairy foods</td>
</tr>
<tr>
<td><strong>Macrocategory: unpleasant gaseous scavengers</strong></td>
<td></td>
</tr>
<tr>
<td>Amine scavengers</td>
<td>General applications. Excellent results with seafoods</td>
</tr>
<tr>
<td>Aldehyde scavengers</td>
<td>Dried and pulverised products; meat-based and vegetable foods</td>
</tr>
<tr>
<td>‘Broad-range’ scavengers</td>
<td>Vegetable foods</td>
</tr>
</tbody>
</table>

Active devices may be produced and applied in different ways (adhesive films, bags, capsules) depending on specific packaged products.

The main function of scavengers is clear (see Section 2.1.9). The continuous elimination of residual and produced gases into containers has to be seen as the natural evolution
of modified atmosphere techniques [38]. As an example, oxygen may be absorbed into polymeric matrices containing ferrous compounds, organometallic salts or particular enzymes (glucose oxidase or ethanol-oxidase). As a result, all chemical and enzymic reactions that need oxygen to run quickly are highly decelerated according to Piergiovanni [40]. This solution may be a cause of collateral microbial spreading by anaerobic microorganisms. Because of this risk, oxygen scavengers are generally used to control and enhance shelf-life values of dried and low-moisture foods.

Residual and unacceptable moisture can be completely adsorbed as reported by Piergiovanni [40] by silica gel or glycerol (\( \text{C}_3\text{H}_8\text{O}_3 \)) or lowered to acceptable values with KCl and NaCl (application: vegetable products). It should be noted that common salts are less expensive than other solutions.

For carbon dioxide and ethylene adsorption,\( \text{CaCl}_2 + \text{NaOH} \) (or KOH), and \( \text{Al}_2\text{O}_3 + \text{KMnO}_4 \) or zeolites mixtures are employed respectively, with good or excellent results.

Active packages may be used to modify the inner atmosphere in contact with packaged foods in different ways, and the complete elimination of certain gases is the easiest way. Another strategy is the increase of particular substances by means of chemical release or generation. The most well-known example is the slow release of ethyl alcohol because of its important inhibitory action against microbial fermentations. Existing solutions are produced with polymeric matrices that are able to release previously adsorbed ethanol into air spaces. This system may also be used (baked products) in a more direct way (release of free ethyl alcohol in the packaging step).

For vegetables, the release of free carbon dioxide is preferred. Mixtures obtained with ascorbic acid and \( \text{Fe}_2(\text{CO}_3)_3 \) can be useful (see Section 2.1.9).

Other types of active packages are able to release anti-microbial, antioxidant or enzymic substances. The inhibition of certain bacteria and microorganisms on fresh fruits and fish products can be produced with nisin or chitosan (antibiotic agents), but other substances may guarantee similar results: synthetic zeolites, aluminium and silver-mixed silicates, ZnO and MgO, according to Piergiovanni [40]. Grain and similar foods can be preserved with anti-oxidant agents while broad-range applications imply the use of enzymic molecules (cholesterol reductase, glucose oxidase).

Finally, active packages can be produced with the aim of releasing particular aromas, colours or ‘active chlorine’. Another possibility is the chemical adsorption of unpleasant gases.

For active devices, related failures should be discussed and associated to the ‘main’ package and its own defects. Separate arguments may not be clear for FO. Several examples have been shown and explained in Chapters 8 and 9 with the aim of showing
that the entity of failures caused by active objects can be understood in relation to ‘main’ packages only.

### 2.6 Intelligent Packages

Intelligent packaging is produced to collect, store and communicate particular information about packaged products [36, 37]. Similarly to active packages, intelligent devices are not strictly coincident with the normal idea of containers but should be considered as external accessories only.

Intelligent packaging is able to:

1. Detect storage conditions (temperature, relative humidity) in correlation with the time (minutes); or
2. Make evident the decrease in quality of the packaged food; or
3. Detect storage conditions and quality decrease at the same time; and
4. Store all the relevant information and/or modifications.

Nowadays, intelligent solutions can be subdivided into two categories for food and beverage applications [37].

The first group concerns all instruments that are able to record and store important variations of quality and functional features [37]. Storage temperatures are the most important variable with HACCP implications. As a result, different intelligent systems are produced with the aim of monitoring thermal changes. Other variables are the partial pressure of inner $O_2$, relative humidity, and so on [37]. All monitoring systems – radio-frequency-identification, nanobarcodes, and so on – have two important features:

1. Strong IT support is strictly required to allow the collection and storage of data [37].
2. Benefits are strictly linked to food logistics areas, with particular reference to possible damage ‘on the road’, according to Jaripomas and co-workers [41].

In relation to logistics, other interesting innovations have recently concerned the possibility to replace the ‘first in, first out’ (FIFO) strategy with more practical procedures that are based on ‘remaining shelf life’ (RSL) values [42]. All records may be indirectly linked to food alterations without the possibility of expressing qualitative or quantitative declarations about shelf life or food safety.
The second group of intelligent materials is able to highlight storage anomalies and consequent food alterations. In other words, the above-mentioned RSL can be evaluated and measured during the whole commercial life of food products. It should be noted that these indicators are easily understandable by retailers and consumers without specific training [37].

Clearly, the second category is more interesting from the HACCP angle. Four subclasses can be defined within this group [43]:

f. Temperature indicators.
g. Time-temperature indicators (TTI).
h. Leakage indicators.
i. Freshness indicators.

These instruments should be [37]:

1. Easily activated.
2. Able to exhibit measurable and reproducible variations that are linked to the remaining quality of foods.
3. Absolutely irreversible.

Time-temperature indicators are exclusively able to record excessive values of storage temperatures in an irreversible way according to Parisi and Piergiovanni [37, 40]. Time-temperature indicator record storage temperatures and are able to add cumulatively their fluctuations by integration during the commercial life of foods. As a result, RSL values can be calculated by this ‘thermal history’ [24] and shown visually. It should be remembered that shelf life is associated to the evolution of the general quality of products, assuming that this is a synergetic sum of \( n \) factors [27].

Generally, TTI show RSL decays in a colorimetric way. All FO and consumers are able to understand this system and its practical consequences by means of simple explanations. Figure 2.26 shows the so-called ‘bull’s eye’, an indicator that displays RSL decays by means of a circular zone filled with diacetylenic monomers. These substances are ready to initiate long polymerisation chains [37]. As a consequence, appreciable chromatic alterations are produced, which are easily readable with or without optical scanners and able to be correlated to different remaining quality values (Figure 2.26). It has to be highlighted that the initial activation has to take place in the final packing step. Consequently, bull’s eye indicators have to be kept frozen until the final use [37]. Normal application targets are fresh and frozen products.
Other TTI show chromatic alteration in a ‘chromatographic’ way or by means of enzymatic indicators [43]. However, it should be considered that FO are not in agreement about the reliability of ‘chromatographic systems’ [37].

Time-temperature indicators are the newest frontier of monitoring devices because of numerous benefits [37]:

1. The ease of use and reading by the normal consumer.
2. The possibility of ‘just in time’ and ‘shortest remaining shelf life’ strategies instead of FIFO.
3. The objective compliance with Codex Alimentarius, Step 9, Principle 4 – every critical control point has to be continually inspected – and HACCP-based quality standards.
4. The observed trend in favour of minimally processed and ‘assembled’ foods.

In addition, every analytical report can be correctly evaluated because of the direct connection between the thermal history of examined foods and related results, according to the first law of food degradation [24]. On these bases, several studies about cheeses have been conducted with the aim to create predictive software products. ‘Deductive evaluation of shelf life: cheeses’, 1.0.1 and 1.0.2 versions, shows these concepts in a mathematical way [33–35].
Concerning possible failures, TTI may not be fully reliable since different foods show different alterations. In other words, TTI and other intelligent devices are designed with reference to the contained food and its own characteristics (specific microbial ecology, colours, seasoning methods and possible variables, and so on). This situation is clearly an important inconvenience because different risks have different weights.

Consequently, new replica indicators have been proposed with the aim of removing this objection [37]. These devices may mimic the composition of packaged foods. In addition, the composition may be obtained with different substances, so that ‘One Food, One Replica’ holds true [37].

Other intelligent objects, similar to gas scavengers and generators (see Section 2.6), can perceive the presence of undesired O₂ and/or CO₂ into MAP packages [38] by means of redox indicators (methylene blue, and so on) or acid/base systems and the consequent revelation of active components [37]. However, these ‘leakage indicators’ can show the following failures:

a. Incorrect O₂/CO₂ values depending on pre-existing microbial spoilage. Consequently, this variable – which is very important in MAP products – has to be taken into account before standardising and evaluating related results [37].

b. Incorrect results because of incorrect storage of these indicators (fixed at 5–8 °C in order to prevent the anticipated reactions).

Finally, ‘freshness’ indicators allow detection of the production and consequent accumulation of gaseous substances (H₂S, ammonia, tri-methylamine N-oxide, acetic acid) by microbial spoilage [37, 40, 44]. These systems have obtained good results despite the fact that they are considered extraneous or incompatible with fresh foods by normal consumers.

Concerning intelligent devices, related failures should be discussed and associated to the ‘main’ package and its own defects. Separate arguments may not be clear for FO. Several examples have been shown and explained in Chapters 8 and 9 with the aim of showing that the entity of failures caused by intelligent and active objects can be understood in relation to main packages only.

2.7 Temporary and Functional Packages

This section has been included in Chapter 2 because FPM are generally recognised as permanent containers up to the commercial consumption of contained products and consequent declassification to packaging waste. The world of food packaging should be extended to so-called functional and temporary containers. These adjectives
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cern the specific role assumed by these materials within commercial and industrial companies. These packages are no different from permanent containers from the HACCP viewpoint. Consequently, all discussions about manufacturing and related failures have already been mentioned in previous sections.

The first category – functional packages – includes all food-contact approved materials with the following features:

1. These materials have strong or weak similarity with permanent containers.

2. These objects are designed to make part of a processing machine (they cannot be used as permanent containers).

3. Consequently, food contact is not protracted (maximum storage: a few minutes).

The second group – temporary containers – includes all food-contact materials that have been designed to contain intermediate food products concerning chemical composition, appearance, shapes, colours, and so on.

Consequently, all containers (plastic moulds, and so on) that may be used to contain food products with a well-defined shape are functional packages. On the other hand, each container that may be used to carry out a particular function – semihard cheeses may be immersed in highly salted solutions with small vessels – has to be considered as a temporary package.

Plastic bags may be considered as functional objects if they are used to weigh and/or mix different components (example: citric acid or sodium citrate in processed cheeses). Finally, all biodegradable and normal shopping bags must be classified as temporary containers if used by consumers as surrogate containers to pack fruits and vegetables in hypermarkets. Single-use plastic gloves should be considered as functional bags (Figure 2.27).
Concerning temporary and functional packages, the explicit request of compliance to food-contact regulations in accordance with existing HACCP-based ‘Quality Standards’ has to be highlighted (Section 4.3). For example, the ‘Global Standard for Food Safety’ (Clause 5.1) requires that FO have to evaluate purchased FPM with the aim of confirming the effective suitability for the intended uses (on the basis of declarations of compliance by PO). The situation discussed above has obliged most European retailers to request specific warranties with reference to processing machines and their compliance to repealed Directive 89/109/EEC (Section 4.1). In other words, the matter concerns the suitability of processing machinery with reference to food-contact applications, according to EN 1672-2:2009 (food processing machinery basic concepts, Part 2: Hygiene Requirements). This request has to be satisfied by FO.

Consequently, every processing machine (production, packing steps) has to be inspected in relation to all mobile parts with specific functions: Teflon-coated tubes, plastic moulds, removable knives, plastic cylinders, and so on. Migration tests and the simple surveillance (example: detached plastic films from vessels) are required or desirable. Similarly, all mobile instruments (trolleys, and so on) that can be used to store smoked and normal foods (ageing or seasoning step) have to be considered [45–47]. Finally, the category of different vessels and similar containers with the function of temporary storage between the \( n \)th and \( n + 1 \) productions (‘off-line’ materials) has to be remembered.
References


Food Packaging and Food Alterations: The User-oriented Approach


Food Packaging and Food Alterations: The User-oriented Approach