

PACKAGING MATERIALS
7. METAL PACKAGING
FOR FOODSTUFFS



REPORT

Prepared under the responsibility of the
ILSI Europe Packaging Materials Task Force

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By Peter K.T. Oldring and Ulrich Nehring

REPORT
PREPARED UNDER THE RESPONSIBILITY OF THE ILSI EUROPE PACKAGING MATERIALS TASK FORCE

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FOREWORD

The present report is the seventh in the report series on food packaging materials, which was commissioned by the ILSI Europe Packaging Materials Task Force. The report series aims to give a concise overview on specific packaging materials with regard to their uses as packaging material, their basic chemistry, safety and toxicology, regulation and environmental fate. The reports mainly address an audience in the packaging-producing and packaging-using sectors.

Earlier reports have been published on the following topics and can be obtained as a hard copy via publications@ilsieurope.be or be downloaded from:

<http://europe.ilsieurope.org/publications/Report+Series/packaging/packaging.htm>

- PET Packaging Materials (2000)
- Polystyrene for Food Packaging Applications (2002)
- Polypropylene as a Packaging Material for Foods and Beverages (2002)
- Polyethylene for Food Packaging Applications (2003)
- Polyvinyl Chloride for Food Packaging Applications (2003)
- Paper and Board for Food Packaging Applications (2004)

INTRODUCTION

Background

Metal packaging plays an important role in the process of food preservation. The common expression used to describe such a process is “canning”. Canned food has become an important part of the human diet in developed countries during the past century. It is of particular value in those parts of the world where no or limited refrigeration exists for storing food. It is a means of safely preserving foodstuffs without microbiological deterioration.

Metal packaging has a double function as a protection against any external influence on the foodstuff during heat treatment and storage and as a sales and information pack. The basic requirement for such a package is the hermetic tightness of the container. The food, which is sterilised by the heat process, ought to be protected against any re-infection with microorganisms or any other kind of influence from the outside. This rather complex requirement is often described as “container integrity”.

Metals are used for many food contact applications, such as saucepans and coffee pots as well as packaging. This monograph only considers metal packaging for foodstuffs. As many of these contain an organic layer (referred to as coating) on the metal surface between the foodstuff and the metal, the topic of coatings has been given a special emphasis.

Use of metal packaging

Food is packed into a wide range of containers, some of which consist of all metal whilst others have metal components. The different types of metal packaging include:

- Beer and soft drink cans
- Food cans
- Drums and pails
- Aerosol containers
- Tubes
- Open trays
- Caps and closures (e.g. lids on glass jars and bottle tops)
- Lids (e.g. for yoghurt and butter containers).

Food cans are packed under ambient pressure or vacuum whilst beer and carbonated beverage cans are packed under pressure. Another difference is in the processing that occurs once the can is filled and the lid is seamed on. Soft drinks typically undergo no further treatment. Beer is frequently pasteurised in the can. Many foods are filled hot and are cooked in the can, under a wide range of conditions. This gives food that can be preserved for long periods (a 5-year shelf life is not uncommon) without the need for preservatives. The sterilising processes are controlled to assure microbiological safety during the foreseen shelf life.

Use of coatings for metal packaging

Many metal packagings (typically cans, containers, caps and closures) are normally coated on one or both sides. The inside (food contact) coating is referred to as an internal coating, lacquer or enamel and the outside as external coating, enamel, ink or varnish. Unlike many other applications, can coatings are normally thermally processed (stoved or baked). Metal packaging is coated for many reasons:

Internal (food contact) coatings:

- Provide protection of the contents from the metal – e.g. iron pick-up in beer or discolouration of some dark-coloured fruits, such as plums and strawberries, due to metal contact
- Provide protection of the metal can from the contents of the can – e.g. acidic soft drinks (which may corrode uncoated metal) or some fish, meats and soups (which may cause sulphur staining).

External (non-food contact) coatings:

- Provide protection of the metal from the environment – e.g. atmospheric corrosion
- Support decoration, labelling and consumer information
- Influence mobility (friction) of the article during filling operations – e.g. beverage cans can only be filled with an external decoration, which provides the necessary friction (mobility) to pass through the filling head.

For the purpose of this monograph, only internal coatings have been considered.

Coatings influence the manufacturability of the can:

- By reducing tool wear for tin-free steel (TFS) substrates. Tin on the surface of steel (electrolytic tinplate – ETP) “lubricates” the metal during deformation, whereas steel without a tin layer is very abrasive and the presses used for forming would rapidly wear out
- By assisting tooling for aluminium substrates.

Unlike many other industries, practices vary widely – both geographically and on a company-by-company basis. Nonetheless, the typical and general examples of (coated) metal packaging normally encountered are described in this monograph. For various reasons, some countries or companies will use a particular type of metal, can or coating for a specific end use, whilst other countries or companies may use alternatives for the same end use. A single can may consist of different metals and a number of different or similar internal coatings.

METALS AND ALLOYS USED FOR FOOD PACKAGING

Aluminium

Aluminium is widely used in food contact materials (Elinder and Sjögren, 1986; Codex, 1995). Aluminium alloys used for food contact may contain elements such as magnesium, silicon, iron, manganese, copper and zinc (CEN, 2004a; CEN, 2004b).

Aluminium and its various alloys are highly resistant to corrosion. When exposed to air, the metal develops a thin film of aluminium oxide (Al_2O_3). The film is colourless, tough and non-flaking and few chemicals are able to dissolve it (Beliles, 1994).

Pure aluminium is attacked by most dilute acids. At neutral pH, aluminium hydroxide has limited solubility. However, the solubility increases markedly at pH below 4.5 and above 8.5 (Elinder and Sjögren, 1986). Uptake of aluminium from uncoated food contact materials is influenced by the acidity of the foodstuff and the solubility of the salt formed. For example, aluminium acetate dissolves easily in 3% acetic acid, but hardly in 1% phosphoric acid, as a protective insoluble layer of aluminium phosphate is formed. High salt concentrations (over 3.5% sodium chloride) can also increase the migration. Aluminium is normally coated for packaging applications.

Steel

Steel grades for food contact packaging applications are essentially electrolytic tinplate (ETP) and electrolytic chromium/chromium oxide coated steel (ECCS), as described in product standard EN 10202:2001 (CEN, 2001).

Electrolytic tinplate (ETP) is a cold-rolled low carbon mild steel sheet or coil coated on both surfaces with tin that is applied in a continuous electrolytic operation. Tinplate can be differentially coated when one of its surfaces carries a heavier tin coating than the other. Usual coating weights range from 1 to 15.1 g/m².

The most common alternative to electrolytic tinplate for food contact applications is ECCS (electrolytic chromium/chromium oxide coated steel)⁽¹⁾, which has equal coating weights on both surfaces of the coil. The function of a chromium coating is to prevent atmospheric oxidation or sulphur staining of the steel by foodstuffs and to improve lacquer adhesion. ECCS is always used with an additional organic coating (i.e. can coating). It is normally used for the manufacture of drawn cans, can ends and lug closures, where welding is not required.

Black plate is a non-alloyed steel substrate used for the manufacture of ECCS or electrolytic tinplate (ETP). Its applications in non-processed form for food contact are limited (e.g. steel drums) and it is not used for mainstream fast-moving consumer goods.

During processing of proteinaceous foods, small quantities of sulphhydryl fractions of the protein are formed. With electrolytic tinplate, black tin sulphide is readily formed if there is inadequate protection of the surface. With ECCS white iron sulphide can be formed – this is also the case for ETP where the tin layer does not cover the iron.

Tin

Tin can be applied as a thin layer on steel used for metal packaging. It is applied electrolytically during the manufacture of ETP (electrolytic tinplate). The tin layer provides corrosion resistance and in some cases is not coated, as tin can act as an efficient oxygen scavenger. However, using uncoated tin is limited by the various possible interactions between the metal surface and the foodstuff and is therefore mainly used for, e.g. light fruits in brine or tomato-based products.

(1) ECCS and the above-described TFS (tin-free steel) are similar concepts that are used alternatively in different parts of the world. ECCS is nevertheless preferred as a denomination in Europe.

TYPES OF METAL PACKAGING

There is an environmentally and cost- driven evolution of metal packaging into thinner metal gauges (i.e. weight of metal in a can), nowadays encouraged by packaging waste regulations (Directive 94/62/EC, 1994), which place emphasis on the minimisation of the material used. Of course, this has to be achieved without compromising the protective aspects of the package. To achieve this, engineering or design changes are made, such as beading (i.e. rings around can bodies) on food cans and the move to smaller diameter ends for some beverage cans (from size 206 to 202 for example). This results in more demanding performance from the coatings, inks and lacquers used.

Metal packaging used for foodstuffs can be arbitrarily divided into cans, pails and drums, aerosol containers, tubes, trays, closures and lids.

Cans

There are in essence distinct types of cans and ends (or lids). The lids are always attached after filling the can with foodstuffs, thus the packers and fillers purchase empty cans and lids and seam the lids onto the cans.

Cans consist of either two or three separate components (“two-piece cans” and “three-piece cans”); while three-piece cans are composed of a cylinder, a top and a bottom end, two-piece cans have the wall and bottom formed out of one piece and a separate top. Their sizes range from very small (a few grams) to catering pack sizes (typically for contents of 2–10 kg).

Two-piece cans (drawn cans)

Most of the drawn cans find usage in the beverage as well as the food industry. Drawn cans are also widely used for packing sweets, and these are usually closed with a slip lid. Both steel and aluminium substrates can be used. A punch is used to deform a disc of metal. Two-piece cans are formed from a blank of metal into a can without a lid.

Drawn cans are produced by unwinding a coil of metal or using panels of metal and stamping discs from it. The metal substrate is usually coated on both sides. The discs are “cupped” to form the shape to a short metal beaker, normally by the use of a high-pressure press. This is the first stage of the deformation to make a can.

These cans are differentiated by the method used to form them:

- Single drawn
- Drawn and redrawn (DRD)
- Drawn and wall-ironed (DWI)
- Drawn and ironed (DI).

Single drawn cans

For shallow cans, a single drawing operation is required. Typical shallow drawn cans are club, sardine, tuna and ready-meal cans. The cans of processed ham are at the limit of a single draw can.

Drawn and redrawn cans (DRD)

For taller cans, such as large salmon cans, two or three operations – draw and redraw (DRD) or multiple redraw are used. Some drawn cans have a larger diameter at the top than at the bottom. The tapered shape enables them to slide into each other for transport, thereby minimising the costs of transporting large quantities of air for large distances. A typical example is the large North American salmon can.

Drawn and wall-ironed (DWI) cans

These cans are used for beer and beverages (B&B). The number of DWI B&B cans manufactured and filled in the EU is more than double that for food cans (as of 2006), by whatever manufacturing technique. They are made from either aluminium or steel. Soft drinks are normally cold-filled and carbonated thereby generating a positive pressure, which serves the multiple purpose of displacing headspace oxygen, producing the characteristic “fizz” and, importantly, providing abuse resistance and strength to the thin-walled DWI can. Post-processing is minimal. Beers are normally pasteurised after filling. This involves heating to about 65°C for 20–30 min and then cooling.

To produce a DWI can, a drawn cup (see above) is further processed to make a cylinder by deforming the sides of the cup by stretching it through dies of decreasing diameter (“wall ironing”). The wall thickness of the can is reduced by “ironing” the metal and consequently lengthening the can.

The process of making a DWI can is similar for aluminium and steel. However, a major difference comes at the stage when the cans are necked (the diameter is reduced at the top of the can). Steel beverage cans utilise more coating and processing options than aluminium ones.

The cans are washed (four to six times) in a multi-stage washer. At this stage, various treatment chemicals can be used in the washers; these may differ for aluminium and steel cans. The washing serves to remove any lubricant from the wall ironing process. Aluminium cans may also undergo a pre-treatment during the washing process to improve the adhesion of the coatings. The last wash is normally with deionised water to create a contaminant-free surface for coating. After drying, the cans are externally decorated. The final stage is the application of the internal lacquer, which is spray-applied and cured in an oven.

Drawn and ironed cans (DI)

This is a variation on DWI beer and beverage cans, but these cans are for food, either human or pet, and are not normally externally decorated.

Three-piece cans

Three-piece cans are mainly used for food, but may be used for some non-carbonated beverages, particularly fruit juices. They were the original cans, consisting of a bottom (end), walls (body) and lid. They are made with ETP only being used for the body, in order to facilitate welding, whilst TFS or ETP could be used for the ends or possibly aluminium if an easy-open end (lid) is used.

The components of the three-piece can are cut from steel after coating (if used). The wall of the can is rolled to form a cylinder and the seam (joint) is welded. A protective lacquer is then applied to this seam. It can be either liquid or powder and is known as a side seam stripe. A bottom (either a classic or easy-open end) is then attached. After filling, a lid (classic end) is attached to close the can. Both the bottom end and the lid have a gasket applied to ensure a hermetic seal.

Earlier technology soldered instead of welded the side seams of the can bodies, which resulted in lead contamination of the contents. This practice started to cease in Europe in the early 1980s and has been replaced by welding all over the world today. Soldered cans are not traded internationally anymore. The use of a pure tin solder is retained for a few very specific applications.

In some types of three-piece cans, the side seam is crimped rather than welded or soldered. Non-welded seams are either folded or interlocked folded. A gasket could be used for sealing. This does not apply for the standard food can that is sterilised.

It should be noted that some three-piece food can bodies, particularly those with ETP bodies, are not internally lacquered, but their TFS ends are. However, three-piece cans to be filled with dry food, e.g. milk powder, instant baby food, sweets or roasted nuts, are usually not coated at all on the internal surface.

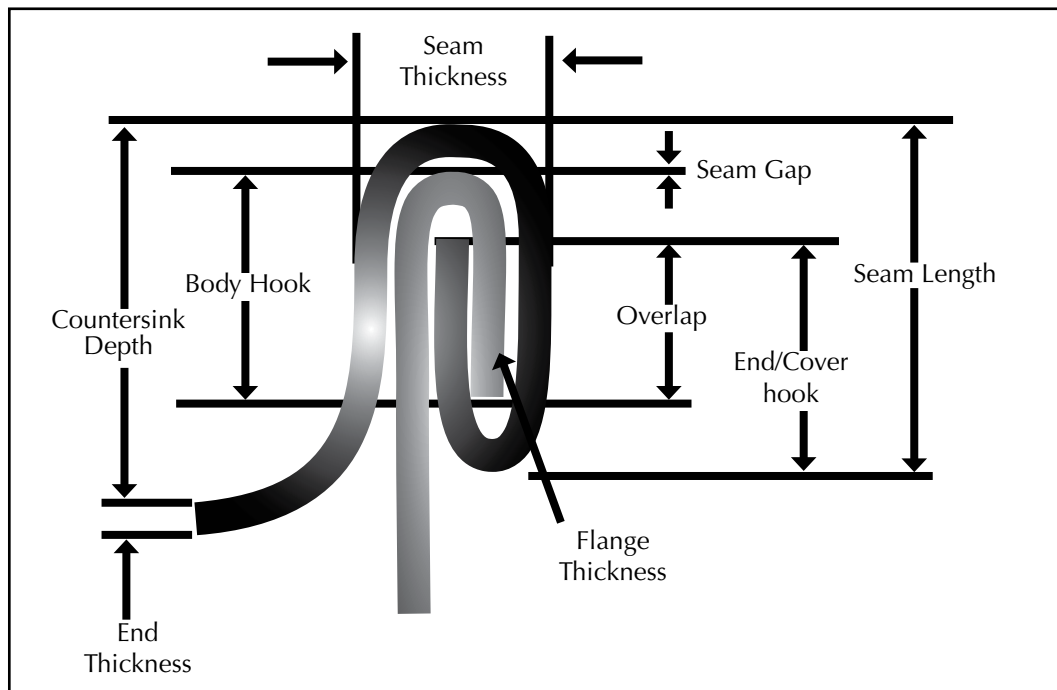
Dry foodstuffs such as biscuits or tea are available in tin boxes. These are in essence a cylindrical or rectangular three-piece can. The lid is not seamed on but is formed as a “slip on” or “plug” lid. The food is not processed in such boxes.

Can ends

The lids are always attached after filling the can with foodstuffs, thus the packers and fillers purchase empty cans and lids and seam the lids onto the can.

The ends on a can are seamed onto the body to give a hermetic seal. The lid is seamed on when the can is filled. The exceptions are open top cans (for example sweet or biscuit tins). A double seam is shown in Figure 1. Many of the dimensions are critical to ensure that any potential microbiological ingress is minimised (can integrity).

Figure 1: Double seam



Classic ends

The classic end, normally used for food rather than beverages, is circular and most have circular ridges, which are expansion rings to allow for any changes in volume of the food during the thermal processing. For classic ends, TFS or ETP are normally used.

Easy-open ends

Easy-open ends (EOEs) are becoming ever more popular. Not only do they avoid the inconvenience of having to use a can opener but also, due to their design, they are much safer with fewer lacerations caused by the edges of the jagged end produced by a can opener.

All DWI beverage cans, regardless of whether they are steel or aluminium, have an aluminium end.

There are many types of ends used for food cans. The full aperture easy-open end (FAEOE) is gaining widespread acceptance. In this type of end, all of the end of the can lid is effectively removed during the opening process, unlike a beverage end where only part is opened and stays on the end or is separated from the end, to enable the contents to be poured from the can. Ends for food cans can be made from aluminium, ETP or TFS. Whilst designs and metals may differ, the principles of manufacture are similar: The metal is coated. A shell is punched and then the EOE shape is fabricated, including the score line that weakens the metal sufficiently to allow its fracture and easy opening. A tab is then attached to the end by a rivet. This rivet is drawn from the can end (to ensure microbiological integrity) – a most demanding deformation process – to ensure the integrity of the end. A repair coat can be used to repair the damage caused by scoring and forming the rivet.

Easy-peel ends are also beginning to affect the market for easily removable ends.

Drums and pails

Drums and pails are in essence large three-piece steel cans. They are supplied empty, with bungs in the “lid” for the customer to fill. They are not subjected to any processing when filled. Drums tend to refer to larger volume containers of typically 100–220 l whilst pails normally refer to 5–25 l containers. There are different grades of drums depending upon the intended contents and method of transportation.

Aerosols

Aerosol cans are mainly used for non-food applications, such as cosmetics, body care products, insecticides and lubricants. Only a few foodstuffs, such as canned whipping cream, are packaged in an aerosol.

Aerosol cans are either three-piece or two-piece. In essence, the principles of two- or three-piece can manufacture apply, whilst the ends differ and are fitted as a unit. All three-piece aerosols are made from steel. The main difference between aerosol and can manufacturing is with the two-piece aerosol, known as a monobloc. The aerosol container is manufactured of aluminium by impact extrusion. The diameter of the open end is reduced (swaging) to receive the spray nozzle and an internal lacquer is spray applied. Typical rates of production are about one fifth of those of a DWI B&B can process, partly due to the parameters surrounding the application of the internal spray.

Based on two-piece aerosol can technology, a recent development is an aluminium bottle for beverages.

Tubes

Metallic tubes are extruded from a slug of metal (mostly aluminium). Not all tubes are internally lacquered, particularly toothpaste tubes. Many tubes are no longer based on metal. Only those tubes with contents necessitating minimal interaction with oxygen are metal based.

Trays and foils

Rigid and semi-rigid aluminium trays for food application are based on rolled aluminium (with different alloys) of a thickness in the range 70–300 μm . In some cases, containers with polyolefin laminate structures together with polyurethane adhesives are used for the food contact side of the tray to provide retort resistance.

Closures

Closures are used to seal containers. They can be re-usable/re-sealable as in a lid for a jar of pickles or bottle of ketchup or bottle of whiskey, or they can be one-way as in a crown bottle top for beer. Closures need not be made of metal, and plastics are making significant inroads into this market. Some people, particularly in the regulatory arena, refer to some closures as lids, particularly those closures for jars.

The inside of a closure is usually coated. On top of that coating a gasket may be applied. It must have sufficient flexibility and deformability to ensure an airtight seal. In addition, any components in the gasket material should have minimal migration (see Chapter on Regulatory Aspects, page 24). In some cases, both coating and gasket are in contact with the foodstuff; in other cases only the gasket is in contact.

Closures can be divided into:

- Crowns
- Vacuum lug closures
- Aluminium closures on bottles.

Aluminium closures can be subdivided into two groups, namely pre-threaded and roll-on. In the latter case, the threading is performed during the closing operation in contact with the glass or plastic bottle.

Crowns

Crowns are the traditional bottle tops that are removed with a bottle opener. Either ETP or TFS can be used as the substrate. Depending upon the geographical location, old or new technology may be encountered. The major difference is in the sealing insert, which covers the beverage contact surface of the crown. It is either a liner made from plastic (polyethylene or an ethylene, vinyl acetate copolymer) or a compound made from a plastisol (PVC), which is expanded into a foam to enable it to seal the bottle. The former is the new technology. A few drops of molten plastic are dropped into an upturned crown and pressed to form the beverage contact surface internal surface. With a plastisol, the crown is spun to spread the plastisol. Normally, there is no intended direct contact between the coating of a crown and the contents of the bottle. It is only the compound that makes contact with the foodstuff.

A newer development is the twist-off crown. Instead of the flutes, a thread is made in the crown, which can be twisted off by hand and is re-sealable. The same coatings and compounds described above are normally used.

Vacuum closures

Vacuum closures are metal tops for jars and sauce bottles (mostly glass). They are sometimes referred to as closures or "twist-off" closures. There is a range of different types and not all have lugs. A lug is that part of the metal lid which is used to screw the lid onto the glass thread. These lug closures are normally classified by their diameter and depth (RTO regular twist-off closure, MTO medium twist-off closure and DTO deep twist-off closure). The PT (push-twist) cap does not have any lugs and relies on a compliant compound for retention on the jar threads and maintenance of a hermetic seal. The lids on baby food jars are an example of a PT closure. Tamper-proof variants (buttons etc.) of many of the caps and closures are available.

With these metal closures, PVC compounds (gaskets) are applied on top of the coated metal to enable an airtight seal between the glass and the metal to be achieved. The interactions between compound and internal lacquer are very complex. It is necessary for the gasket to adhere to the coating and not all coatings are compatible. Thus, the coating and gasket have to be selected together as a package. Different contents and processes require different compounds and internal lacquers. The compound is applied hot (molten) and the cap is spun to evenly distribute the compound, with the thickest part being at the highest centrifugal force part of the cap (the edge) where it is needed.

Recently there have been issues (formation of trace amounts of semicarbazide formed from azodicarbonamide) in the EU surrounding the materials used in gaskets for certain types of closures (vacuum lug and PT closures). This has resulted in the azodicarbonamide Directive 2004/1/EC (amending Directive 2002/72/EC on plastic materials in contact with food) and specific restrictions on the use of plasticisers in PVC sealing gaskets for vacuum closures used for glass jars. Gaskets must be flexible and as most consist of PVC they need hydrochloric acid scavengers, as hydrochloric acid can be formed during dehydrochlorination of the PVC. In addition, gaskets need to be expanded when the jar is filled in order to obtain the optimum airtight seal. The additives used in order to satisfy these criteria have resulted in the recent problems in the EU of migrating species.

Aluminium closures on bottles

These are the tops found on bottles of spirits, some carbonated drinks and sterilisable bottles (medicines). They are based upon aluminium for ease of formability and tearability. The threads of these caps are formed when they are rolled onto the bottle and are tailored to the glass thread. They can also be pilfer-proof (in order to easily show if someone has tampered with the contents) and the terminology used in industry is given in the Glossary. Normally there is no direct contact between the metal coating and the contents of the bottle, but only with the inlay in the closure. Typically, there is a wad between the coating and the beverage

Lids

While lids on glass jars and bottle tops are referred to as caps and closures (see above), this part of the chapter deals with the kind of lids used for yoghurt and butter containers.

Sealed lids close a tray hermetically and prevent external influence on the foodstuff. In most cases these lids enable the food pack to be easily opened. For this purpose, aluminium foil of 20–70 µm is used after the rolling processes. There may or may not be a pre-treatment process for the metal.

CAN COATINGS

Introduction

Can coatings are applied to metal and after thermal treatment (cure schedule or stoving) form a dry (final) film on the metal. Most coatings are applied as a wet film. The major constituents in a can coating as applied to the metal include:

- Resin(s)
- Cross-linking agents (almost always present)
- Additives
- Solvents (not always present).

The first three components are incorporated into the dry (final) film. In case a solvent is used, it evaporates during the cure schedule. The film, which is in contact with food, must comply with relevant food regulations as discussed in the Chapter on Regulatory Aspects, page 24. Unlike plastics, coatings form a very thin film of between 1 and 10 μm , about a twentieth of the thickness of a sheet of paper. In some cases, solvent-free coatings (e.g. powder side seam stripes) are used, albeit at higher film weights.

As an alternative to applying coatings on metal, thermoplastic films can be either laminated or extruded onto the metal and the coated metal formed into cans or can components. Such “plastic films” may consist of e.g. polypropylene, polyethylene terephthalate, polyamide (nylon) or a polypropylene/nylon co-extruded combination. For the purpose of this monograph, only coatings have been considered that form a dry film after application have been considered, rather than those that are, essentially, a film before application.

Unlike most plastics, the majority of coatings only attain their final properties after the wet (applied) film has undergone further chemical reactions, normally during the cure schedule. Typically the resin(s) would react with one or more cross-linking agents (or resins), which join individual resin molecules together to form a three-dimensional cross-linked network. It is this network and the density of cross-links in combination with the different molecules used in the resins that give the corrosion resistance and flexibility, amongst other properties, of the final film. Even coatings that primarily contain thermoplastic resins, such as PVC, normally have a small amount of a cross-linking agent/resin present to further improve the performance of the coating.

Different metals may require different coating systems. As examples, soft drink cans made from ETP (electrolytic tinplate) normally have a different coating to those made from aluminium. TFS (tin-free steel) food can ends need both internal and external coatings for protection, unlike ETP.

Applying and curing coatings

Internal coatings for metal packaging are typically applied by either roller coating or spraying before undergoing a cure schedule (stoving or baking). The metal to be coated can be shaped as a sheet, coil or preformed object. As in many cases the coatings are applied before deformation of the metal to form the container or cap, the coating has to withstand severe mechanical deformations (e.g. for lug closures, crowns, ends and some shallow drawn cans). In other cases, the coatings are applied after forming the object, but nearly always further deformation is required before the final object is obtained, e.g. necking a DWI can. It is not unusual to apply more than one internal coating or to apply one type of coating several times. Each internal coating would be cured before the application of the next one.

The major differences between coil- and sheet-fed are the line speeds and curing conditions. Coil lines have short dwell times for the coating in the oven, but high temperatures, due to their high speeds (e.g. 100 m/min), whereas typical sheet-fed ovens have relatively low line speeds and consequently lower oven temperatures.

The speeds of production can be very high with over 2,000 DWI cans being produced per minute or up to 6,000 sheets (each 1 m²) being coated and cured per hour, although in practice many lines run below these rates with about 1000–1500 DWI cans/min or 4,500–5,000 sheets/h being typical.

The cure schedule varies from application to application. Because internal lacquers are primarily intended for protection, the cure schedules for internal lacquers tend to be more severe and longer than those used for external systems. Typically, industry defines the cure schedule necessary to ensure a specified performance as peak metal temperature (pmt). This is the minimum metal temperature at which a coating must be held for a specified time and is often given as a cure window, e.g. 195–205°C for 10–12 min for a sheet-fed product and perhaps 10–20 s at 270–230°C for a coil-coated product. Each coil line is different and requires different conditions.

The amount of a coating applied to the metal packaging is quoted in weight per area (e.g. g/m²) or weight per can (e.g. mg/can). This weight refers to the coating remaining on the metal after curing. Weight per area is normally used for sheets, i.e. for food applications, whereas weight per can would be used for preformed objects such as beverage cans. For food, the range is typically 5–15 g/m² and for beverages weights in the range 110–180 mg/33 cl can would be typical, depending on whether the can was aluminium or ETP and whether beer or soft drinks were to be packed.

Chemistry of can coatings

There are a limited number of different chemical functionalities available for direct food contact coatings, resulting in a limited number of different types of resins that can be used for coatings for metal packaging. However, there are many variations of each type. The different resins consist of monomers and starting substances, which have to be approved by regulatory authorities (see Chapter on Regulatory Aspects, page 24). The resins discussed here are all approved for food contact, albeit with restrictions. The main types of resins are given in Table 1.

Table 1: Types and properties of resins used in internal can coatings

	Nature	Flexibility	Pack resistance	Main end-uses
Epoxy-phenolic	High molecular weight epoxy resins cross-linked with phenolic resole resins	Good	Very good	Universal gold lacquer for three-piece cans Shallow drawn cans
Organosol	PVC dispersed in an appropriate varnish and conventionally stabilised with a low molecular weight epoxy resin or novolac epoxy resin. Epoxidised oils can also be used	Very good	Very good	Drawn cans Easy-open ends Often used over epoxy-phenolic basecoat.
Epoxy-anhydride	High molecular weight epoxy resins cross-linked with anhydride hardeners	Good	Very good	Internal white for three-piece cans
Epoxy-amino	High molecular weight epoxy resins cross-linked with amino resins. Also epoxy acrylic water-based spray internals for B&B DWI	Good	Limited	Universal lacquer for beer and beverage cans (water reducible) Side seam stripes Some food systems
Polyester	Polyester resins cross-linked with amino or phenolic resins. May contain lower molecular weight epoxy resin	Very good	Pack- dependent	May not be suitable for very acidic and aggressive foods
Phenolic	Phenolic resin(s) which self-crosslink (cure)	Very poor, but film quality is weight-dependent	Excellent, particularly for aggressive foodstuffs	Drums and pails where flexibility is not a critical factor
Oleoresinous	Naturally occurring oils with synthetic modification	Variable	Pack- dependent	Very limited uses

Epoxy resins, based upon bisphenol A (BPA) and epichlorohydrin, have been used in coatings for light metal packaging since the 1950s and are the single most widely used class of resin in use today for metal packaging, with epoxy phenolic coatings finding the largest application. Epoxy resins are cross-linked through both their hydroxyl and oxirane functionalities, using phenolic or amino resins and occasionally an anhydride oligomer. Before curing, they typically vary in molecular weight from about 360 to 6000 Da (Dalton). The lowest molecular weight epoxy resin used is BADGE (bisphenol A diglycidyl ether) and, as this is reacted with further bisphenol A to increase its molecular weight, a hydroxyl functionality is introduced in addition to the epoxy (also: "oxirane") group at each end of the linear molecule.

For most applications the higher end of the molecular weight epoxy resins are used. The exception to this was the use of low molecular weight liquid epoxy resins (BADGE) in PVC organosols. This practice has largely been superseded due to regulatory issues within Europe.

PVC-based coatings, organosols, have been successfully used for many years. They are mainly thermoplastic in nature, but normally require both plasticisation and stabilisation – roles that epoxy resins successfully fulfil. In order to optimise performance of a PVC coating, resins may be added that are based on vinyl chloride copolymerised with other monomers, some of which can react with other components in the coating. Epoxidised novolac resins, also referred to as novolac glycidyl ethers (NOGE), were used extensively in the USA in organosols, both as plasticisers and as HCl (hydrochloric acid) scavengers to prevent potential corrosion of the metal due to potential dehydrochlorination of the PVC. Following an opinion of the SCF (EC Scientific Committee on Food), which stated that the use of NOGE in organosols was inappropriate without further toxicological testing; the European can industry stopped using NOGE in this type of application.

Polyesters have only been used for a restricted number of coatings to date, but they are gaining wider acceptance. At present, they do not possess the universal properties of epoxy-based systems and more types of polyesters are required to fulfil all of the roles currently met by epoxy-based systems. Polyester-based coatings can be thermoplastic, as used in side seam stripes, or they can undergo cross-linking reactions (typically through their hydroxyl functionality) with a number of systems, such as phenolic resins, amino resins (particularly melamine formaldehyde resins) or poly-isocyanates. The higher the number of hydroxyl groups available for reaction, the greater the potential cross-linked density of the cured film. Increasing cross-link density typically decreases flexibility, but increases chemical resistance.

Amino resins are based on the reaction products of urea, melamine or benzoguanamine with formaldehyde and frequently a low molecular weight aliphatic alcohol. Their prime use in coatings for metal packaging is as a cross-linking resin for either epoxy or polyester resins. Amino resins are normally complex mixtures, partly because they typically undergo some degree of self-condensation reaction during their manufacture. During the curing process, they react with functionalities in the other resins present in the coating, as well as undergoing some self-condensation reactions, which can give rise to "clusters" of amino resin moieties in the cured coating.

Phenolic resins are based upon the reaction products of phenolic monomers such as phenol, cresols, xylenols or mixtures of these with formaldehyde and frequently a low molecular weight aliphatic alcohol. Their prime use in coatings for metal packaging is as a cross-linking resin or adjuvant; however, they can undergo self-condensation (cross-linking or curing) reactions without any other resins being present. Phenolic resins are complex mixtures, partly due to self-condensation reactions occurring during their manufacture. Whilst phenolic resins will self-condense to give a chemically resistant film, the resulting flexibility is very limited and for most applications phenolic resins are "plasticised" with epoxy resins, with which they react yielding a cured film.

Anhydride oligomers can be used to cross-link epoxy resins. They are typically based upon the reaction product of trimellitic anhydride with an aliphatic glycol, such as ethylene glycol. The anhydride functionality is retained. Many white coatings, particularly for maize (sweet corn) cans, are based upon epoxy resin cross-linked with anhydride oligomers.

Oleoresinous-based coatings find little general usage today, although there are some specific applications. They were widely used before being superseded by epoxy resin based coatings. Being based on natural substances, they tend to cause issues with organoleptic quality when used for some foodstuffs. Oleoresinous materials are made from naturally occurring oils and fatty acids. Some examples of the resins are a chemically inert, unsaponifiable petroleum hydrocarbon resin with some unsaturation in combination with tung oil, which is predominantly composed of oleostearic acid plus smaller amounts of oleic, palmitic and stearic acids. Another resin combination commonly used is a maleic-modified glycerin ester of tall oil rosin plus heat-bodied dehydrated castor oil.

Coatings obtain their final colour in various ways. Epoxy phenolic coatings normally generate a "gold" colour when cured due to the chromophores in the phenolic resin. Indeed, epoxy phenolics are often referred to as "gold" lacquers and colour can be used as an indication of degree of cure for a given system. The white coatings are made by the addition of titanium dioxide, often in an epoxy anhydride coating or sometimes an organosol. Aluminium is added to a coating to give a grey "aluminiumised" appearance to the final film.

For more detailed information on the chemistry of coatings for metal packaging, see Oldring, 2001 and Paul, 1997.

Coatings for different types of metal packaging for foodstuffs

Many of the requirements of the metal packaging and the coating system are related to the products to be packed. The main conditions encountered are for the following products:

- Beverages – soft drinks, beers, fruit juices, teas etc.
- Wet food
- Dry food.

Coatings for beverage cans

Many soft drinks are extremely acidic, being based upon phosphoric acid, and as such corrosion of the can is potentially a serious problem. Since all carbonated beverages are packed under pressure, it is vital that internal coatings provide complete protection to the can, without blemishes or flaws. Soft drinks are more aggressive than beer, thus higher film weights are used. Beer presents problems of its own in that its flavour suffers by contact with many coating systems and particularly by the slightest trace of contamination with iron or tin. The internal lacquer prevents migration of aluminium.

DWI beverage cans are sprayed with a water-based epoxy acrylic system, normally with an amino resin for cross-linking. For steel beverage cans, some phenolic resin may also be present, unlike for aluminium beverage cans, to further strengthen the polymer matrix against iron and tin dissolution. Steel cans have higher film weights than aluminium cans for the same beverage

Three-piece tinplate beverage cans can be coated with an epoxy amino basecoat applied by roller coating, followed by a coating containing PVC, vinyl chloride copolymer resin or a PVC-free top coat applied by spraying inside the formed can to ensure that the film is completely unbroken. Alternatively, an epoxy phenolic basecoat with an epoxy acrylic internal spray could be used.

Aluminium easy-open ends are predominately used for DWI for beverage cans. They are based on vinyls or organosols but "PVC-free" ends are now widely being used, particularly in North America and Europe. There are a number of different types of resins that are currently used in coatings for easy-open ends for beverages, ranging from epoxy to polyester or combinations thereof. Solvent-borne and water-reducible beverage end coatings are available.

Coatings for food cans

Due to the fact that many canned foods are thermally processed in the can after filling, canned foods, as distinct to other forms of foodstuff, place some of the most demanding requirements on the coatings. As these requirements differ widely, a more diverse range of coatings is found in comparison to all other forms of foodstuffs in metal packaging.

The biggest variation in coating properties relates to the type of food, due to the large number of different foodstuffs packed and their individual requirements and processing conditions. The most demanding foods are meat, fish, high-sulphur vegetables (peas and sweet corn), highly acidic foods (sauerkraut and rhubarb) and highly coloured foods (red fruits and curry).

As food is often heat processed in the can, the coatings, both internal and external, must withstand the conditions. Also, the internal lacquers must be resistant to the contents of the can during processing and any by-products, such as hydrogen sulphide, formed in the food during the processing. In addition, migration of components of the coating layer should meet the restrictions of the applicable legislation (see Chapter on Regulatory Aspects, page 24).

The bulk of the food can coatings are based upon epoxy resins, primarily epoxy phenolics (internal gold lacquers for food cans) and to a lesser extent epoxy anhydride (white internals for food cans), with PVC-based organosols being the next most-used category (organosols finding larger usage in North America than in Europe). For all coatings an epoxy phenolic basecoat may be used, e.g. for a food can easy-open end.

Vegetables, meat, soups and fish are slightly corrosive and, where sulphur staining could be a problem, can ends are normally coated with zinc oxide-modified epoxy phenolic lacquers. Aluminiumised epoxy phenolics are increasingly used for solid meat packs. The use of epoxy phenolics has some advantages over oleoresinous lacquers (which tend to soften during retorting), such as the promotion of meat-release properties, an important factor in meat packs. Content release is also assisted by incorporation of waxes and silicones in order to help, e.g. solid meat or fish to slide more easily from the can by preventing the contents from sticking to the sides of the can. In these cases, the wax is known as a "meat release agent" and lacquers using these waxes are widely used for luncheon meat, pâté and fish roe.

Cans do not always need an internal coating. Some packs of vegetable oils, particularly large catering tins (5 l), may not be coated, but their ends may be. Uncoated ETP cans are used for specific food types, including tomatoes and other tomato-based products, white fruits and some vegetables (e.g. mushrooms, asparagus). Uncoated cans are preferred to lacquered cans in situations where a small lacquer discontinuity (e.g. scratch) would result in a concentrated attack of the base steel (the small area of tin would quickly disappear) and could potentially lead to pin holing and microbiological contamination. For many acidic products, the presence of tin is desirable because it eliminates oxygen, which would otherwise cause discolouration of the contents. Additionally, for many tomato-based products, the presence of a bare tin surface inside the can leads to protection of the natural flavour and appearance of the food, through oxidation of the tin surface in preference to oxidative degradation of the food. This process retains the quality attributes that consumers expect from these products throughout their long shelf life. Fully lacquered cans do not allow this flavour to develop. It should be noted that whilst the ETP body may be uncoated, if TFS ends are used they would always be coated.

Lacquers for sulphur-bearing foods

When considering sulphur-bearing foods it is always important to make a clear distinction between solid and liquid packs. In summary, the general rule is that sulphur-absorbing lacquers are used for vegetable and liquid packs but sulphur-resisting lacquers (i.e. barrier coatings) are used for solids packs of meat or fish.

Solid packs include ham, luncheon meat or solid fish such as tuna, which are not in a covering liquid. This type of product requires a lacquer, which will present a barrier to the sulphur products in the pack and will therefore prevent sulphur blackening of the tinplate. For many years phenolic lacquers, as the sole binder, were the generally accepted standard for sulphur resistance and they are still used for a range of these products. However, a change to the epoxy-phenolic blends has been made particularly for luncheon meats and fish packs. This has been due to the fact that epoxy-phenolic lacquers have greater resistance than phenolics to the polyphosphates and other preservatives that are now added to such packs. Epoxy-phenolic lacquers on the other hand have rather less resistance to sulphur than pure phenolics and it has become normal to incorporate aluminium pigment in the coating in order to mask any eventual sulphur staining that may take place on the surface of the tinplate. In view of the flexibility of epoxy-phenolic blends, these aluminium-pigmented lacquers are suitable for both three-piece and shallow drawn cans.

Packs for liquid foods (or foods covered with liquid) that are rich in proteins, including vegetables such as peas or beans, shellfish and also some soups, are dealt with in a different way: During sterilisation, the sulphur products that are formed in the pack (particularly hydrogen sulphide) can move freely through the liquid and are particularly concentrated in the headspace of the can. If a barrier-type coating is used, the volatile sulphur products in the headspace may produce an unpleasant smell when the can is opened. For this reason, it is important to absorb and neutralise the sulphur compounds that are liberated in the pack.

There are two ways to absorb and neutralise the liberated sulphur compounds. The first is to use a lacquer pigmented with zinc oxide to absorb odorous sulphides liberated during and after retorting. During sterilisation the lacquer softens under the influence of heat and this permits the sulphur compounds that are formed in the pack to react with the zinc oxide. The reaction produces zinc sulphide, which is white in colour and harmless. It is possible to use this type of lacquer on the bodies and ends of cans, but it is normal to use phenolic or epoxy-phenolic lacquers on the bodies in order to have a better resistance to scorching along the side seam during the welding and side seam striping operation and to use the zinc oxide-containing lacquer on the ends. The quantity of zinc oxide in the lacquer on the two ends of the can is usually sufficient to absorb and neutralise the sulphur compounds liberated in vegetable packs such as peas or beans. For products such as sweet corn (where lacquers were specifically developed to overcome

sulphur staining) and shellfish, which have a higher sulphur content, it is normal to use pigmented lacquer over the whole of the can. As tinned corn was first to give rise to the problem of sulphur staining, the term "C-lacquers" was coined in the USA (from C = corn) as opposed to R-lacquers for other purposes (R = regular). Acidic products should not be permitted to come into contact with lacquers containing zinc oxide because the reaction may produce zinc salts that could destroy the continuity of the film.

The second method, widely used for liquid-vegetable packs, is simply to leave the body of the can unlacquered. The sulphur products are removed by being absorbed on the surface of the tinplate, which consequently becomes blackened. This gives an unpleasant appearance and in order to reduce the effect, the ends of such cans are sometimes lacquered, so that when the can is opened it has a clean and hygienic look.

Acidic fruits

Acidic fruits need to be packed in (partly) lacquered steel cans; aluminium cans are not suitable. It is necessary to distinguish between (i) fruits that have a clear juice and (ii) fruits that have a red or bluish juice.

Examples of fruits with a clear juice are pears, peaches, pineapples and yellow plums. They are normally packed in ETP cans with unlacquered can bodies, but with lacquered TFS or ETP ends and applied side-stripe lacquer in order to protect the welded side seam of the can against corrosion. If some of these fruits were packed in completely lacquered containers, the covering liquid might become cloudy or discoloured through oxidation.

In the case of coloured fruits that contain anthocyanin pigments, such as strawberries, raspberries, blackberries, black cherries and red plums, the fruit must be packed in a totally lacquered can because the juice will be quickly discoloured by contact with tin or iron, thus every effort must be made to prevent all contact between the juices and the metal surface.

It is not difficult to develop lacquers that have good acid resistance, but it is difficult to apply a perfectly continuous film of lacquer in one coat and avoid scratches and defects caused by handling the empty cans. For some packs this is not important, but in an acid pack pinholes form the centre of attack and the contact between the juice and tin or iron will eventually cause discolouration of the contents and a gradual undermining of the lacquer film. For these packs, it is necessary to apply two coats of lacquer, where the second coat effectively covers any imperfections in the first coat. Epoxy-phenolic lacquers are normally used.

Apart from coloured fruits, double-lacquered cans are used for other strongly acidic foods such as pickles, gherkins, cucumbers and beetroot. Also, tomato concentrate is packed in double-lacquered cans, while whole peeled tomatoes and tomato juice are normally packed in unlacquered cans for reasons of taste and oxygen scavenging.

While these comments represent normal practice, there are certainly specific cases that do not so readily fall into this pattern.

Closures

Closures can be divided into many groups and the internal coating requirements will depend on the substrate, closure design and pack. Depending upon the type of closure and product, jars may be steam-evacuated and the closure twisted on. Processed foodstuffs, be they in cans or jars, normally will be under vacuum once they have cooled down. This helps in the preservation of the product by limiting the amount of oxygen in the headspace. Whilst it is difficult to give specific examples the following acts as a general guide.

Vacuum closures

Lug Caps (Twist-Off® type) normally contain a plasticised PVC gasket and may be used with almost any food pack ranging from jams to pickles to vegetables in oil. For jams and preserves, a single coat of an epoxy phenolic lacquer or an organosol is adequate, while pickles demand at least a two-coat system. In this instance, an epoxy phenolic basecoat is normally used followed by an organosol topcoat to give PVC gasket adhesion. Plasticised PVC gaskets need additives in order to prevent their degradation, ensure hermetic seals and aid the application. There have been some issues in Europe concerning migrants from PVC gaskets as regards the plasticisers, the blowing agent and other additives used.

Baby-food closures can be sealed with either a PVC gasket (PT, push-twist type) or a rubber ring, depending on the closure design. Full retorting (sterilisation) properties are required in addition to product resistance. Normally an epoxy phenolic basecoat is followed by one or two coats of an organosol.

Push-fit closures for preserves normally have a single coat of vinyl in order to provide the required gasket adhesion and resistance properties. Where high SO₂ content (>20 mg/l) packs are being used, either a double coat of vinyl solution or a single coat of organosol could be used.

For screw closures for dry food, gasket compounds are not generally used and are usually replaced by a cardboard or composite wad. Protection from microbiological contamination by the use of a hermetic seal (needed during processing of the contents of wet foods) is unnecessary for most dry powders; they only require an airtight seal. An internal coating is often present to prevent tool wear. A typical example in this class is coffee closures, which are normally coated with an epoxy phenolic gold lacquer.

Aluminium closures

Roll-on closures (RO) are the most important group of aluminium closures and can be further subdivided into pilfer-proof and non-pilfer-proof groups. A typical example of a roll-on closure is that used on bottles of spirits. The choice of coating will obviously depend upon the product being packed. A phenolic acrylic lacquer is used with a full gasket (covering the whole food contact surface) for carbonated drinks, whilst for high acid resistance either a two-coat system (epoxy phenolic + vinyl) or a three-coat system (two coats thermosetting vinyl + one unmodified vinyl) is normally used. In the above examples, the lacquers are not in direct contact with the beverages.

The majority of pilfer-proof closures are used on spirit bottles and have a wad in place of a PVC compound. Their size can vary from those used on miniature bottles to those on deep-skirted ones. Generally, unmodified vinyl lacquers are successfully used either pigmented with titanium dioxide or a suitable dyestuff. Vinyl coatings of this type have no water resistance (i.e. they will not pasteurise). When pasteurising properties are required, for example with beer, a PVC liner would be used in conjunction with a phenolic/acrylic lacquer. This combination of properties is never required on deep drawn roll-on pilfer-proof (ROPP) closures.

Pre-threaded closures are often used on pharmaceutical packs and may require sterilisation (they are not normally lined with a gasket). A thermosetting vinyl system is commonly used for this application.

General line containers

Although the field covered under this rather vague heading is very wide, wet foodstuffs are not involved and the choice of internal coating systems becomes rather more straightforward, if indeed one is needed at all.

Tinplate is sufficiently resistant to be used unlacquered for most general line applications. Tin-free steel and black plate may be specified for larger containers for reasons of economy and in certain cases an oleoresinous or phenolic internal lacquer is used.

Aerosols

The aerosol ends are usually severely tested and tough coatings of high flexibility are needed, for example, an epoxy phenolic basecoat followed by a vinyl top coat.

The choice of coatings for the bodies depends on the contents. A double coating of an epoxy phenolic or one of epoxy phenolic and one of a phenolic are typical for three-piece aerosols, and an organosol typical for monobloc aerosols.

Tubes

Tube coatings are normally based upon epoxy phenolics.

Drums and pails

Coatings for drums and pails normally consist solely of phenolic resins, as these are self-cross-linking to give a corrosion-resistant film, albeit with limited flexibility. However, flexibility is normally not a prerequisite for this type of packaging.

Trays

Various types of materials are used to coat aluminium trays for food contact applications, including lacquers based upon epoxies, polyesters, polyacrylics, polyvinylchloride copolymers, polyvinylacetate copolymers and polyurethanes. Heat-seal lacquers, such as polyvinylchlorides, polyacrylics or others, enable container-lid combinations for closures. They are applied with a physical drying process at less than 200°C. These coatings provide a chemical resistance of the metal against foodstuff components for the retort processes and minimise any metal migration into the foodstuffs.

Lids

For lids a wide variety of heat-seal lacquers are used; one is an adhesive layer to enable the lid to be sealed onto the tray, although it may not cover the whole of the food contact surface. Similar to tray coatings, the coatings for lids are mainly based on polyacrylics or poly-methacrylics, polyvinylchloride copolymers or polyolefin types. Laminated metal can also be used.

REGULATORY ASPECTS

The regulatory status for can coatings in contact with food is far from clear today. The USA has a well-known and universally accepted system, which has been in use since the mid-1950s. In Europe, the situation is evolving and differs between countries from non-existent to specific legislation such as in The Netherlands.

Today (2007) there is no specific harmonised European regulation for can coatings, with the exception of the use of certain epoxy derivatives under Commission Regulation (EC) No 1895/2005. Instead, national regulations are relevant. In addition, compliance with the Framework Regulation (EC) No 1935/2004, applicable to all food contact materials and articles is essential. This Regulation sets the basis for safe food contact materials. The Council of Europe developed Resolutions for several food contact materials not already covered by harmonised EU legislation. Resolution AP(2004)1 for coatings in contact with food sets a good standard for bringing safe metal coatings to the market.

FDA requirements for direct food contact lacquers

Most food companies require that any product intended as a coating on metals for direct food contact must comply with 21 CFR 175.300 (resinous and polymeric coatings) of the US FDA Regulations. 21 CFR 175.300 consists of a list of permitted substances and materials with any relevant restrictions. This is in addition to any local regulations that may also apply.

The FDA defines several categories of foodstuffs, with different requirements. The respective CFRs need to be carefully consulted to understand possible compositional requirements for the respective food types. For compliance testing, a list of test conditions required for each type of foodstuff to measure extraction with food simulants (ether, water, heptane or 8% ethanol) is given. Maximum limits for extractives (global migration) in relevant simulants have been established and refer to the chloroform-soluble part of the dry residue of the extract.

European Community regulations

Coatings are listed in Annex I of the Framework Regulation (EC) No 1935/2004 as a category of food contact materials for which a specific regulation may be established. As a result of the highly specific process technology applied to make a final metal coating it was understood both by industry as well as the European Commission that coatings should be regulated separately from plastics. A specific European harmonised legislation for this category of food contact materials still needs to be developed.

Toxicological acceptance of used substances (Regulation (EC) No 1935/2004)

Like any other food contact material, metal packaging intended to come into contact with foodstuff has to be in compliance with the overall requirements of the EU Framework Regulation (EC) No 1935/2004. According to Article 3 of this Regulation, the following essential requirements must be met:

- No transfer of packaging constituents to food in quantities that might endanger human health
- No unacceptable change in the composition of the food
- No deterioration of the organoleptic characteristics of the food.

It is within the responsibility of the manufacture to demonstrate compliance with Article 3 of the Framework Regulation. In order to do so, the following approaches should be considered.

In the absence of any specific Community legislation for coated food contact materials, the national legislation of EU Member States applies, where it exists. To ensure that coatings comply with Article 3 of the Framework Regulation, Member States often apply restrictions by the European Food Safety Authority (EFSA) on substances toxicologically evaluated in the context of plastics intended to come into contact with foods. Only a small proportion of the substances used for plastics are also used in the rather complex world of coatings chemistry. Therefore, only a restricted number of substances, needed to manufacture food contact coatings, have been toxicologically evaluated by EFSA or in the past by the Scientific Committee on Food (SCF). Some Member States have their own legal requirements on substances used for food contact and have applied their own toxicological assessment to these substances.

Migration limits (Commission Directive 2002/72/EC)

In the absence of national legislation on coated metal packaging, Member States apply, where suitable, provisions on plastic food contact materials according to Commission Directive 2002/72/EC (Plastics Directive) and its amendments. Substances used in metal coatings, but regulated by the Plastics Directive, or by national legislation in certain Member States, have to meet the applicable specific migration limits (SML) mentioned in this legislation.

Overall migration (OM) tests on metal packaging are usually carried out according to the protocols of Council Directives 82/711/EEC, 85/572/EEC and 93/8/EEC, which have been established specifically for plastics. The overall migration limit of 10 mg/dm² or 60 mg/kg specified for plastics in Commission Directive 2002/72/EC is usually applied to surface coatings as well. CEN has published guidelines on testing OM on polymeric coatings on metal substrates (CEN/TS 14235:2002), which suggests that for overall migration there is no need to test with 3% acetic acid, but only 10% ethanol or distilled water. In addition, alternative simulants for fatty foods can be used in place of olive oil.

Regulation gap: laminated metal packaging

Currently the legal situation in the EU for laminated metal packaging is almost similar to the one for coated metal packaging. However, laminated structures containing at least one layer that is not plastic are expressly not covered by Commission Directive 2002/72/EC and its amendments to date. Although the Plastics Directive is suitable for most of the plastic layers of laminated metal packaging, there are still gaps in the current legislation, for example with regard to adhesives used for the manufacture of this type of food contact materials. Where it exists, national legislation should be applied to demonstrate the legal compliance of components for adhesives.

Epoxy Derivative Regulation (EC) No 1895/2005

In 1996, migration levels above those permitted in the Plastics Directive 90/128/EEC for bisphenol A diglycidyl ether (BADGE) were detected in some canned foodstuffs, especially in fatty foodstuffs such as sardines in vegetable oil. The can coating industry successfully improved their epoxy-based products in the following years in order to reduce the concentration of low molecular weight epoxy components migrating from the final lacquer film. Epoxy derivatives, in particular BADGE, its hydrolysis products and hydrochlorine adducts, have been examined with respect to their toxicological profiles.

Commission Directive 2002/16/EC (last amended by Directive 2004/13/EC) was superseded by Commission Regulation (EC) No 1895/2005 reflecting the EFSA opinion (EFSA-Q-2003-178, 2003) on the use of certain epoxy derivatives in materials and articles intended to come into contact with foodstuffs. This Regulation restricts the use of certain epoxy derivatives in food contact materials and articles as follows:

- a. The total migration of bisphenol A diglycidyl ether (BADGE) and its derivatives BADGE.H₂O and BADGE.2H₂O into foods must not exceed a limit of 9 mg/kg.
- b. The total migration of BADGE.HCl.H₂O, BADGE.HCl and BADGE.2HCl into foods must not exceed a limit of 1 mg/kg.
- c. The use and presence of bisphenol F diglycidyl ether (BFDGE) in the manufacture of food contact materials and articles is prohibited as from 1 January 2005.
- d. The use and/or presence of novolac glycidyl ethers (NOGE) in the manufacture of materials and articles are prohibited as from 1 January 2005.

Commission Regulation (EC) No 1895/2005 does not apply for containers with a capacity greater than 10,000 l and pipelines.

National legislation on metal coatings

Only a few EU Member States have specific legal provisions on metal packaging or surface coatings intended to come into contact with foodstuff. The Dutch “Verpakkingen- en Gebruiksartikelenbesluit” contains the most detailed specific national regulation on surface coatings within the EU. The Dutch positive list of substances that may be used for the manufacture of food contact coatings is widely used by industry to demonstrate to other EU Member States the legal compliance of coated metal packaging with Article 3 of the Framework Regulation (EC) No 1935/2004. Other EU Member States that have specific legal provisions on some aspects of surface coatings include France, Belgium, Italy and Greece.

The following EU Member States have specific legal provisions or official recommendations on metals for food contact applications: Austria, Finland, France, Germany, Greece, Netherlands, Norway and Sweden. These provisions mainly cover the transfer of heavy metals from metallic food contact articles into foodstuff.

A general overview of national legislation in place is listed on the EC website http://ec.europa.eu/comm/food/food/chemicalsafety/foodcontact/eu_nat_laws_en.pdf. It also states specific national legislation on coatings in the five Member States mentioned before.

Council of Europe

Resolution AP(2004)1 on surface coatings

In 2004, the Council of Europe (CoE) published Resolution AP(2004)1 on surface coatings intended to come into contact with foodstuffs, which superseded Resolution AP(96)5. Can coatings are incorporated into this Resolution.

An inventory list of substances (monomers and additives) actually used, along with their national or European status is given, including restrictions such as a specific migration limit. In addition, there are generic descriptions of how these monomers may be combined to produce resins and how they are used in the coatings. Indications of the functional groups present are also given. A Good Manufacturing Practice (GMP) Guideline Document is also appended.

The framework document of the coating resolution contains the following specifications:

Coatings used for food contact applications under normal or foreseeable conditions of use should meet the following conditions:

3.1. They should not transfer their constituents to foodstuffs in quantities which could endanger human health, or bring about an unacceptable change in the composition of the foodstuffs or a deterioration in the organoleptic characteristics thereof.

3.2. They should be manufactured in accordance with guidelines on good manufacturing practice for coatings intended to come into contact with foodstuffs and using compounds of "Technical document No 1: List of substances used in the manufacture of coatings intended to come into contact with foodstuffs" as well as aids to polymerisation as set out in "Resolution AP(92)2 on control of aids to polymerisation (technological coadjuvants) for plastics materials and articles intended to come into contact with foodstuffs" or relevant national regulations, and prepared, applied and cured in strict adherence to manufacturer's specifications, according to the conditions specified.

3.3. They should not transfer their constituents to foodstuffs in quantities exceeding 10 mg/dm² of surface area of material or article (overall migration limit). However, this limit should be 60 mg of the constituents released per kilogram of foodstuff in the following cases:

- Articles which are containers or are comparable to containers or which can be filled, with a capacity of not less than 500 ml and not more than 10 l*
- Articles which can be filled and for which it is impracticable to estimate the surface area in contact with foodstuffs*
- Caps, gaskets, stoppers or other similar devices for sealing.*

3.4. They should not transfer migrating components not referred to under Article 3.2 of MW <1000 Da in quantities that could endanger human health. These non-listed compounds of MW <1000 Da should be subjected to appropriate risk assessment, taking into account dietary exposure and toxicological structure activity considerations.

In addition, the inventory list of substances used has also been approved by the CoE. This list represents the substances used for direct food contact applications that are approved by national authorities. It is subdivided into four lists: (A) monomers and other starting substances fully evaluated by the Scientific Committee on Food (SCF) and classified in SCF lists 0-4; (B) monomers and other starting substances approved only by national authorities including the US FDA; (C) additives on SCF lists 0-4; (D) additives with national approvals including US FDA. There is a need for re-evaluation of those substances appearing in the temporary annexes, which will require several years. Two other technical documents are also in preparation: an annex on resins, (pre-polymers, used as reaction intermediates) and a risk assessment document on coatings.

It is anticipated that many of the solutions for issues surrounding coatings in contact with food arising from the CoE Coatings Resolution will be incorporated into a future EU Coatings Regulation/Directive.

Guidelines on metals and alloys from metal packaging

In 2001, the Council of Europe published a Technical Document called 'Guidelines on Metals and Alloys used as Food Contact Materials'. The Guidelines cover a wide range of metals and alloys that are used in contact with foodstuff or that may occur as impurities of food contact materials. For each metal, the Guidelines contain information concerning the application in food contact materials, migration properties, the toxicological profile and conclusions regarding possible restrictions in the use of the metals or alloys as a food contact material.

Industry chain initiative: "Code of Practice" for coatings in food contact

In the absence of a harmonised EU legislation for coatings for light metal packaging, industry has prepared a Code of Practice for coatings in direct contact with food, which will encompass coatings on light metal packaging and other coating applications. Some coating applications and laminated metal are outside of this Code of Practice. In these cases, they are deemed to be covered by other regulations. It is envisaged that compliance with this Code of Practice will demonstrate, to any interested parties, compliance with Article 3 (on safety) of the Framework Regulation (EC) No 1935/2004. This industry initiative is a joint project with representatives from all involved in the supply chain as well as food companies. The Code of Practice incorporates principles from the Framework Regulation (EC) No 1935/2004, Council of Europe Resolution AP(2004)1, Commission Directive 2002/72/EC and its amendments as well as new concepts, such as the no migration principle, use of exposure and (Q)SAR (quantitative structure–activity relationship) for risk assessment for compliance with Article 3 of the Framework Regulation (EC) No 1935/2004. The latest information can be obtained from the European Council of the Paint, Printing Ink and Artists' Colours Industry (CEPE, <http://www.cepe.org>).

The Code of Practice is based upon lists of substances in Technical Document No 1 of AP(2004)1 and its amendments. These lists are amended periodically. Whilst all have approval at EU or national level (including US FDA), a significant number have not undergone full review by EFSA and proposals are made for prioritisation of their assessment. In addition to listed substances, non-listed ones can be used provided they fulfil three conditions: (i) they migrate $< 10 \mu\text{g}/6 \text{ dm}^2$; (ii) they are not CMRs Classes 1 or 2; (iii) the Declaration of Compliance accompanying the coating contains a statement that the no migration principle is used. Substances that are both food additives (as listed by the CIAA in an Annex) and potential coating components (dual use) must be declared if they are used as an additive or, if used as a monomer or other starting substance, they migrate above $10 \mu\text{g}/6 \text{ dm}^2$.

The traceability requirements of Framework Regulation (EC) No 1935/2004 and the good manufacturing practice of GMP Regulation (EC) No 2023/2006 must be followed. The Declaration of Compliance (D-o-C) follows the requirements of 2007/19/EC (IVth Amendment of 2002/72/EC). In addition to dual use additives and the no-migration principle, on request the D-o-C should mention if substances not on SCF lists 0–4 are present. Substances with restrictions will be declared in the D-o-C, but not their trade name. Thus, the can-maker will receive from its coating supplier a list of substances present in the coating, without any reference to their sources. The OML and SMLs and other restrictions in 2002/72/EC and its amendments as well as the Synoptic Document will be followed. However, alternative test methods for 3% acetic acid, as laid down in CEN TS 14235-2002, should be used for OML.

Annexes describe the potential chemistries of the resins that could be used in coatings and their potential functional groups. A glossary is also given, as coating terminology is frequently technological. Non-intentionally added substances (NIAS) are treated by the use of exposure. If the structures of other potential migrants are known then structural activity (SAR) alerts or Cramer classes are invoked, as is a threshold of toxicological concern (TTC).

Other legislation concerning metals in food

With respect to a SCF opinion of 12 December 2001 the following limits were set for inorganic tin in foodstuffs with Commission Regulation (EC) No 242/2004:

- Canned foodstuff, excluding beverages 200 mg/kg
- Canned beverage, fruit and vegetable juice 100 mg/kg
- Baby and infant food, special dietary foodstuff 50 mg/kg

Commission Directive 2004/16/EC describes requirements for sampling and analytical test methods used in the public enforcement of the new inorganic tin limits.

At international level, a similar harmonisation process is on-going in the Codex Committee on Food Additives and Contaminants (CCFAC): Codex Alimentarius specifies a maximum limit of 250 mg/kg for tin in certain canned foods including asparagus, tomato concentrates, peas, pears, pineapple, fruit cocktail and apricots. A maximum level of 250 mg/kg also exists for preservative-free juices and nectars including orange, grapefruit, lemon, tomato and pineapple juices and peach and pear nectars. A maximum limit of 150 mg/kg applies to other fruit juices and nectars including apple, grape, blackcurrant and nectars of certain small fruits.

SAFETY EVALUATION

Polymers (surface coatings, lining compounds)

Starting substances (monomers and additives) used for the manufacture of food contact polymers for metal packaging such as resinous surface coatings, laminated plastic films, lining compounds and seaming compounds usually have all been subjected to a risk assessment procedure in order to ensure that no harm to human health could occur if the starting substances were to migrate into food in amounts exceeding their specified limits.

As for surface coatings and compounds there is no established harmonised legislation. Within the EU the toxicological evaluations for the starting substances were partly carried out according to national requirements, e.g. Dutch Warenwet, former German Recommendation XL of the BgVV Plastics Commission, French Food Safety Agency Evaluation or US FDA. For those starting substances that are also used for the manufacture of plastics, toxicological evaluations are available, which were carried out by the Scientific Committee on Foods (SCF) according to the EU protocol as laid down in the Note for Guidance and Practical Guide of DG SANCO. Further details can be obtained on the Commission web site: http://europa.eu.int/comm/food/food/chemicalsafety/foodcontact/documents_en.htm. Starting substances receiving a favourable opinion are usually placed in the Authorised List of Commission Directive 2002/72/EC and its amendments.

Metals

Aluminium

Because aluminium, when used as a component of food packaging, is in most cases covered by a polymeric film (surface coating or laminated plastic film) the level of migration of aluminium even into acidic foodstuff is extremely low. There is no indication of any adverse health effects caused by aluminium in concentrations that may occur due to migration from packaging material.

JECFA (33rd meeting, 1989) recommendations concerning total aluminium ingestion (including food additive uses) are a provisional tolerable weekly intake (PTWI) of 7 mg/kg bw/week equivalent to 1 mg/kg bw/day (or 60 mg/day/adult). The SCF (1990) gave the same PTWI as JECFA.

Tin

Tin may migrate into foodstuffs, especially in those cases where acidic foodstuffs are in contact with plain tinplate. Depending on the size of the can, the tin concentration in the foodstuff may reach levels around 200 mg/kg.

There is no indication of a chronic toxicity of tin in humans because there is no accumulation in the organism (traces in the bones > soft tissues). The acute toxicity of tin is rather low and, according to a recently published study, tin levels up to 267 mg/kg in foodstuff do not cause any harm to the health of adults. It should be noted that there is a great variation in the sensitivity of individuals to tin. Different levels for chronic and acute toxicity of tin could be established.

In 1989, JEFCA established a 'provisional tolerable weekly intake' (PTWI) for tin of 14 mg/kg bw/week, which is equivalent to 120 mg/adult/day. The Committee was of the opinion that the available data for humans indicated that inorganic tin at concentrations of >150 mg/kg in canned beverages or >250 mg/kg in canned foods may produce acute manifestations of gastric irritation in certain individuals. However, dose levels greater than 700 mg/kg are devoid of toxic effects in other cases. Tin levels in cans must be restricted to those consistent with the application of Good Manufacturing Practice.

In 2005, JEFCA concluded that the data available indicated that it is inappropriate to establish an acute reference dose (ARfD) for inorganic tin, since whether or not irritation of the gastrointestinal tract occurs after ingestion of a food containing tin depends on the concentration and nature of tin in the product, rather than on the dose ingested on a body-weight basis. Therefore, the Committee concluded that the short-term intake estimates were not particularly relevant for the assessment, as they were estimated likely doses of total inorganic tin (JECFA, 2005). Therefore, ingestion of reasonably sized portions containing inorganic tin at concentrations equal to the proposed standard for canned beverages (200 mg/kg) may lead to adverse reactions. No information was available as to whether there are subpopulations that are particularly sensitive for such adverse reactions. The Committee reiterated its advice that consumers should not store food and beverages in open tin-plated cans.

In addition, the Committee noted that the basis for the PMTDI (provisional mean tolerable daily intake) and the PTWI established at its 33rd (JECFA, 1989) and 55th (JECFA, 2001) meetings was unclear and that these values may have been derived from intakes associated with acute effects. The Committee concluded that it was desirable to re-assess the toxico-kinetics and effects of inorganic tin after chronic exposure to dietary doses of inorganic tin at concentrations that did not elicit acute effects.

Moreover, the SCF, during its 130th meeting in 2001, concluded that available data do not allow for a maximum upper limit for tin to be deduced. However, they concurred with the JECFA conclusion that 150 mg/kg in canned beverages and 250 mg/kg in other canned foods may cause gastric irritation in some individuals. In the absence of data, it could not be determined whether infants are more sensitive than older children or adults.

Lead

Since soldering of metal packaging has been almost completely replaced by welding, the transfer of significant quantities of lead from the metal surface to foodstuffs is no longer an issue in Europe. Due to the replacement of former lead-containing solder by pure tin solder, even the few soldered cans that are still on the market do not pose any lead problem to the consumer.

Exposure

In the EU it is assumed that 1 kg of food is consumed per person per day and that this 1 kg is packaged in a cube of 1 dm³ in all the same packaging. All restrictions in place today use this assumption. This is a quite conservative estimation for migrants specific to can coatings or coatings. Hence, industry undertook a *per capita* assessment (Dionisi and Oldring, 2002) of the amount of canned foodstuffs consumed and the surface area of its packaging.

The *per capita* consumption of canned foods was 1.1 cans/person/week, equating to 62 g/person/day or 22.6 kg/person/year. The area of the packaging for canned food was 0.55 dm²/person/day. This is substantially below the EU assumption of 6 dm²/person/day. However, packaging loyalty could skew any *per capita* data, because a consumer may only consume a beverage in a particular package (a can for example), thus packaging loyal consumers have been excluded from this discussion. Although it is clear that *per capita* consumption, particularly of beverages, is not a true reflection of consumption; the amounts are far below any assumptions being currently used by the EU, thus there are large safety margins even for the high level consumer.

In order for modern concepts, such as the threshold of toxicological concern, TTC (Barlow, 2005), to be applied to migrants from can coatings, it is essential that an exposure-based approach is accepted for risk assessment. To this end, stochastic modelling of exposure to migrants from packaging is currently being developed (Castle *et al.*, 2006; Holmes *et al.*, 2005; Oldring *et al.*, 2006) and an ILSI Europe Packaging Materials Task Force Expert Group on “Guidance for Exposure Assessment of Substances Migrating from Food Packaging Materials” is in the process of developing a guidance document to conduct exposure assessment.

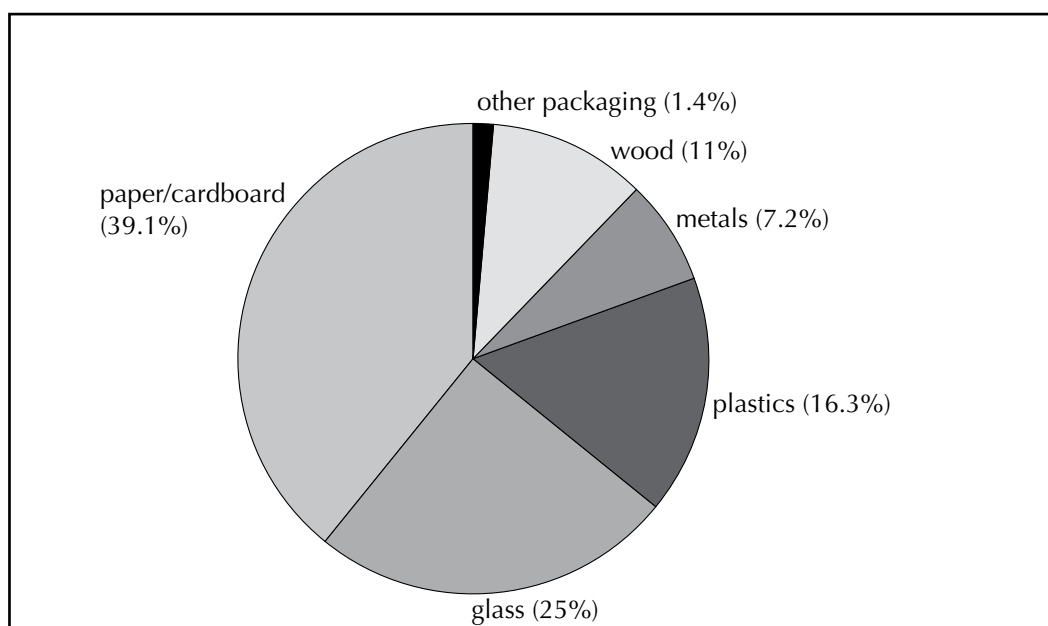
The initial estimates (Oldring *et al.*, 2006) from the model for exposure to BADGE and its regulated derivatives gave an exposure for UK consumers at the 97.5th percentile level, of 0.4–1.4 µg/kg bw/day for the different age ranges and scenarios used. All estimates are well below the new tolerable daily intake value of 150 µg/kg bw/day for BADGE and its two hydrolysed forms, and are also well below the restriction value of 17 µg/kg bw/day for the other regulated BADGE derivatives. The main contributors to exposure were beverages, along with aqueous and acidic foods. This is because of the high consumption of these classes of foodstuffs, even though levels of migration into these foodstuffs and into their appropriate simulants are normally non-detectable. It has been shown that in many cases the main contribution to exposure comes from the value of the non-detectable level and its treatment. Reducing the value used as non-detectable level six fold reduced the estimate of exposure by 40–60%.

The exposure model was used to derive a level of migration of any migrating species, assuming that migration was into fatty foods (“simulant D”) only. The model showed (Castle *et al.*, 2006) that migration up to a limit value in the range 1.6–6.4 µg/dm² (depending on the scenario) would give an exposure of less than 1.5 µg/person/day. Alternatively, if migration into all fatty foods packaged in coated metal was at 50 µg/kg and migration into non-fatty foods was absent, exposure from the consumption of these fatty foods would be in the range 0.9–3.6 µg/person/day. Migration into foodstuffs represented by simulants A and B significantly reduced the levels of migration before a threshold of 1.5 µg/person/day was reached (Castle *et al.*, 2006).

ENVIRONMENTAL REGULATIONS

Metal packaging is, as all other types of packaging and packaging waste, subject to the provisions of Directive 94/62/EC (amended by 2004/12/EC). This directive covers the wide field of packaging, both primary and secondary (i.e. sales, grouped and transport packaging), regardless of their composition. Metal packaging is used in all sectors but with a predominant application as consumer sales packs. The proportion by weight of metal packaging within the total quantity of packaging put on the market is shown as an estimate for the EC countries in Figure 2.

Figure 2: Packaging composition



Source: Commission of the European Communities, 2001

One of the aims of the Packaging Directive 94/62/EC is to reduce the impact of packaging and packaging waste on the environment. One further target of the Directive is to improve packaging waste management and to enhance the recovery and recycling of the packaging material. A schedule is set requiring, in a given period of time, certain percentages by weight of packaging waste to be recycled or recovered.

Due to its magnetic properties, steel is the easiest type of packaging to recover for recycling. It is recycled time and time again without its quality deteriorating. Steel scrap is an essential ingredient in the production of new steel, and markets for steel scrap are virtually unlimited. The recycling rate of steel packaging in the EU reached 60% in 2002.

GENERAL CONCLUSIONS

Metal packaging for foodstuffs includes a very diverse range of products, from cans through closures. Most of the metal packaging has an internal food contact coating, which is essential to the performance of the packaging. Failure of the coating could result in failure of the packaging and consequential spoilage of the foodstuff. Consequently, a wide range of coatings based upon a limited range of approved chemicals is used. In order to resolve some of the issues surrounding migrants from metal packaging that have arisen over the recent years, a workable, European harmonised coating regulation (or code of practice), which utilises exposure, thresholds of toxicological concern and structural alerts, is urgently needed. In the meantime, compliance with the Framework Regulation (EC) No 1935/2004 needs to be demonstrated.

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LIST OF ACRONYMS

ARfD	Acute reference dose
B&B	Beer and beverage (also used in the meaning “beer and soft drinks”)
BADGE	Bisphenol A diglycidyl ether
BFDGE	Bisphenol F diglycidyl ether
BPA	Bisphenol A
CCFAC	Codex Committee on Food Additives and Contaminants
CIAA	Confederation of Food and Drink Industries of the European Union
CoE	Council of Europe
CMR	Carcinogenic mutagenic or reprotoxic substance
Da	Dalton. Unit of molecular (or atomic) weight (e.g. carbon = 12 Da)
DI	Drawn and ironed can
D-o-C	Declaration of Compliance
DRD	Draw redraw can
DTO	Deep twist-off closure
DWI	Drawn and wall-ironed can (used for beverages)
EC	European Community
ECCS	Electro-chromium/chromium oxide coated steel; equivalent to TFS
EFSA	European Food Safety Authority
EOE	Easy-open end
ETP	Electrolytic tinplate
FAEOE	Full aperture easy-open end
FAO	Food and Agriculture Organization of the United Nations
GMP	Good Manufacturing Practice
JECFA	Joint FAO/WHO Expert Committee on Food Additives
MTO	Medium twist-off closure
NIAS	Non-intentionally added substance
NOGE	Novolac glycidyl ethers
OML	Overall migration limit
PMT	Peak metal temperature
PMTDI	Provisional mean tolerable daily intake
PP	Pilfer-proof tops
PT	Push-twist closure (cap lid for jar)
PTWI	Provisional tolerable weekly intake
PVC	Polyvinyl chloride
RO	Roll-on bottle top
ROPP	Roll-on pilfer-proof
RTO	Regular twist-off closure
SAR	Structure–activity relationship
SCF	Scientific Committee for Food of the EC; predecessor of EFSA
SML	Specific migration limit
TCC	Threshold of toxicological concern
TFS	Tin-free steel; equivalent to ECCS
US FDA	United States Food and Drug Administration
WHO	World Health Organization

GLOSSARY

ARfD: An estimate of the amount of a substance in food or drinking water, normally expressed on a body weight basis, that can be ingested in a period of 24 h or less without appreciable health risks to the consumer on the basis of all known facts at the time of the evaluation (JMPR, 2002).

C-lacquers: From C = corn, tinned corn having first given rise to the problem of sulphur staining as opposed to R-lacquers for other purposes (R = regular).

Drum: Large three-piece steel cans, typically 100–220 l.

Lug: The part of a metal lid which is used to screw the lid onto the glass thread. Lug closures are normally classified by their diameter and depth (RTO regular twist-off closure, MTO medium twist-off closure, DTO deep twist-off closure).

Monobloc: Body formed from a single piece of aluminium (e.g. for aerosol cans).

Oleoresinous lacquer: A lacquer prepared by the addition of a resin to a drying oil.

Organosol: A colloidal or finely divided dispersion of particles in an organic liquid, such as when a synthetic resin is dispersed in a plasticiser medium.

Pail: Large three-piece steel cans, typically 5–25 l.

Peak metal temperature (pmt): Minimum metal temperature at which a coating must be held for a specified time.

Pilfer-proof, non-pilfer-proof: While a non-pilfer proof closure can be removed without leaving any evidence that the bottle has been opened, a pilfer-proof closure breaks away from a secure band which remains attached to the bottle.

Plastisol: A vinyl resin dissolved in a plasticiser to make a pourable liquid.

Self-condensation: A spontaneous polymerisation by which two molecules join together, with the loss of a small molecule which is often water. The type of end product resulting from a condensation polymerisation is dependent on the number of functional end groups of the monomer which can react.

Three-piece can: Can consisting of a bottom piece, a cylinder and a top piece.

Two-piece can (drawn can): Can consisting of a beaker-like piece, drawn from a single disc of metal, and a top piece.

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