Copper Development Association

Clear Protective Coatings for Copper and Copper Alloys

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Copper Development Association

Copper Development Association is a non-trading organisation sponsored by the copper producers and fabricators to encourage the use of copper and copper alloys and to promote their correct and efficient application. Its services, which include the provision of technical advice and information, are available to those interested in the utilisation of copper in all its aspects. The Association also provides a link between research and user industries and maintains close contact with other copper development associations throughout the world.

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Copper and copper alloys such as brass and bronze are well known for their strength, corrosion resistance and attractive colours. This range of properties has resulted in their use in a wide variety of applications for both functional and decorative purposes.

In architecture, for example, copper is an ideal roofing material. It is beautiful and durable requiring little or no maintenance and it can be applied easily and economically. It is also comparatively light in weight when considered against other roofing materials, so that savings can be made in the timber substrates. Copper cladding provides an elegant and durable facade to buildings, and copper alloy railings and ballustrades create a sophisticated finish.

Brass is one of the best materials for architectural hardware because of its attractive colour and corrosion resistance. It is widely used for such items as handles and locks and letterboxes. Inside buildings it adds a touch of sophistication to switch plates, socket covers, handrails, taps and lamps along with numerous other fixtures and fittings.

Copper itself and many of its alloys tarnish slowly when exposed to the atmosphere. In some applications, for example roofing, the effect of this gradual colour change is actively sought after. Architects may choose to design with this in mind, knowing that after a few years the roof will have taken on an attractive green patina. It is also possible to produce this patina by chemical treatment, so that the appearance of any stage in the weathering process can be chosen. The surface can be preserved at any stage by the application of a clear protective coating.

A bright polish on brass hardware items can be protected using tough, abrasion-resistant coatings that will withstand daily handling and use. Decorative items also, from inexpensive brass ornaments to unique bronze sculptures, both ancient and modern, can be protected from the atmosphere, and their beauty preserved, by the application of an appropriate clear coating.

There is an enormously wide range of such clear coatings available, many of which are formulated for particular service conditions, and it is essential that the most appropriate coating is chosen for each application. Inappropriate choice of coating will lead to failure in service and rapid deterioration of the appearance of the metal surface.

Copper and Copper Alloys

Copper is used in an unalloyed state or with small additions of alloy elements for a very wide variety of applications. Many uses employ its excellent electrical and thermal conductivities and others result from its strength, malleability and corrosion resistance.

It has been known since prehistoric times that copper can readily be alloyed with other metals giving a range of materials with widely varying, useful properties. The best known of these early materials is bronze, an alloy of copper and tin which is still in wide use today. **Phosphor bronzes** are copper-tin alloys containing small additions of phosphorous. They are known for their excellent wear resistance and good spring properties, and are also used for "copper" coinage. **Gunmetals** are copper-tin alloys with small amounts of other alloying elements used particularly for castings.

The term **"bronze"** can, however, be misleading now because it has become used to cover a number of completely different alloys. **Manganese bronze** is made from copper, zinc and manganese and is really a high tensile brass. **Manganese brass** is a similar alloy but does not have quite such good mechanical properties. Manganese containing alloys can be oxidised to an attractive chocolate brown colour and are often used for architectural purposes. **Aluminium bronzes** are a family of alloys based on copper and aluminium. They have particularly good strength and corrosion resistance coupled with a distinctive pale yellow colour.

Brass is made by adding zinc to copper. Brasses are harder and stronger than copper and are yellow in colour. **Gilding metals** are brasses with less than 20% zinc. They are known for their golden yellow appearance and are used for architectural purposes and for costume jewellery. A large number of brasses are in common use with different amounts of zinc and other alloying elements.

Copper-nickels or cupro-nickels are, as their name implies, alloys of copper with nickel. They have excellent corrosion resistance in the most arduous environments. **Nickel-silvers**, however, contain no silver at all. They are alloys of copper and nickel with some zinc. They are so named because of their white colour.

The coatings described in this booklet are suitable for use on any of these alloys, but for advice on choosing the most appropriate coating it is essential to discuss requirements with the coating supplier.

Surface tarnishing of copper and copper alloys

Despite their excellent resistance to corrosion, polished copper and copper alloys do eventually tarnish on exposure to normal, moist atmospheres. However, the original finish can quickly be restored using recommended metal polishes.

Tarnishing on copper and most of its alloys proceeds with the gradual build up of an oxide film which causes darkening of the surface until a deep brown colour is obtained. Eventually, after a number of years, a green colouration develops due to the formation of copper salts (mainly sulphate and carbonate). This ‘patina’ is protective and self healing and the corrosion rate of the underlying metal is reduced to a negligible amount when the patina is fully developed. All the colours which are developed during the growth of the patina can be reproduced by chemical treatment and this is frequently used to create a particular effect.

Aluminium bronzes and copper-nickel alloys behave rather differently from the other copper alloys. Aluminium bronzes quickly form a strong, tenacious, protective oxide film. It is, therefore, not easy to retain a very bright polish on these materials, but the oxide film will, under normal conditions, prevent the growth of a brown, oxide film, so the attractive, pale golden colour of alloy is retained. Copper-nickel alloys also develop a very stable oxide film which effectively prevents further oxidation of the metal surface, and results in the metal having a dull grey colour. Both aluminium bronzes and copper-nickels are ideal materials for use in exposed positions, especially in marine environments.

Recommendations for the choice of coating

The International Copper Association has funded the development of coatings specially formulated for use on copper and its alloys. This work has resulted in a number of recommendations but the only coating available commercially as a direct result of this work is "Incralac".

"Incralac" is a solvent-based, air drying acrylic resin coating which can be applied by any of the methods commonly used for solvent-based coatings. It contains an addition of benzotriazole which acts as a most effective corrosion inhibitor ensuring that the underlying metal will not tarnish even where the film is damaged. It has a high clarity and is resistant to degradation by ultra-violet light. It was formulated primarily for use by the metal maintenance industry and has been used for such prestige applications as the roof of the Sports Palace in Mexico City which has a surface area of 21,000m2. It has been shown to provide protection for more than 10 years. It is also available for small scale applications such as statuary and domestic items.

Soluble fluoropolymer coatings have recently been developed by a number of manufacturers for architectural applications, and these show dramatically improved durability. Experience of their use on copper and copper alloys is being built up.

"Incralac" and other commercially available coatings based on acrylic resin mixtures have excellent weathering resistance and do not discolour on ageing, but for applications where scratch and abrasion resistance are important it is necessary to use a tougher coating such as one of those based on polyurethane resin. ICA sponsored research has shown that a solvent-based mixture containing a polyurethane resin with a polyisocyanate curing agent, benzotriazole to inhibit corrosion and ultra-violet absorbers will give a long-lasting and durable coating which does not discolour on ageing. The coating must be stoved for 15 minutes at 100°C. Site tests have shown that excellent protection is afforded, even under very severe handling, for at least eight years (ref. 5). This coating was originally marketed as BNF/CB but is not now available under this name. However, most UK coating manufacturers have their own formulations of abrasion resistant polyurethane coatings.

There have been extensive programmes of work to test commercial coatings in America (ref. 2) and Germany (ref. 3) which have recently been summarised (ref. 10). Unfortunately in neither programme of work was it possible to give definitive recommendations, primarily because of the enormous variety of subtlely different coatings on the market. Almost all the commercially available coatings contain a mixture of polymers and a selection of additives. Readers will find sections in this booklet which give further information about aspects of coatings which should help them to make an informed choice for their own application. Table 1 will act as a starting point for general advice on typical applications of different polymer types. In general it can be said that for outdoor applications acrylic coatings or soluble fluoropolymers are most suitable; acrylics are best for decorative items which are handled rarely; and polyurethane coatings are more suitable for applications where the coating is subjected to abrasion and wear, and not likely to suffer prolonged exposure to ultraviolet light. However, there can be no substitute for detailed discussions held with reputable coating manufacturers because only they will have experience of the performance of their own products in a wide variety of circumstances.

The eventual choice of coating will depend on the service conditions anticipated, the type and number of items to be coated, and the method of application of the coating.

Some of the test work (ref. 2, 3, 8) indicates that coatings for brass may need to be different from those used for other copper alloys, but this does not seem to be true in all cases. In all situations the advice of a good supplier will be the most reliable guide.

In general the user can be assured that when the correct choice of coating is made and it is properly applied, long and satisfactory service life can be expected.

Conditions of Service

It is essential that the service conditions are clearly identified before a coating is chosen. It must be stressed that users should discuss their requirements with the coating supplier. The important considerations are to establish:

- whether the coating will be used indoors or outside
- whether the atmosphere will be dry or humid
- the degree of wear resistance required
- the degree of impact resistance required
- whether the coating can be renewed at regular intervals
- whether it is important that the coating has a high degree of reflectivity

Polymers Used for Clear Coatings

There are several different polymers which can be used to make a clear coating. Each one has particular attributes and they may be used either singly or in combination with each other to obtain a coating with the required properties. Most types can be prepared for any of the application methods discussed in this booklet.

The types of polymer are listed and described in Table 1, along with typical areas of application.

Table 1 - Polymers Used for Clear Coatings

Polymer	Film Properties	Typical application
Acrylic	Available in air-drying or thermosetting compositions, acrylics are relatively high cost materials. The airdrying modifications are popular for exterior applications. The thermosetting types are useful for applications requiring high resistance to heat and abrasion. The addition of a chelating agent such asbenzotriazole gives good protection against tarnishing occurring under the lacquer.	Since the thermosetting coatings are not easily stripped off for re-coating, they are not normally suitable for major architectural applications. The copper roof of the Sports Palace in Mexico City is covered with Incralac, an inhibited air-drying acrylic lacquer formulated also with an ultra-violet absorber.
Modified acrylic	Acrylic resins can be modified with polyisocyanate, polyurethane, amino and other resins to produce crosslinked systems with good mechanical strength, abrasion resistance, flexibility and adhesion.	These lacquers are durable and have good resistance to chemicals.
Epoxy	Epoxy coatings have excellent resistance to wear and chemicals. They are relatively expensive and are available in thermosetting or two-part compositions, the latter having a relatively short pot life. They are good for severe indoor applications, but they darken in a few months of exterior service.	Outstanding adhesion and protection for copper surfaces used indoors.
Modified epoxy	The most important combination partners are phenoli or amino resins for improving elasticity, impact resistance, hardness and abrasion resistance.	Ideal for severe service such as bathroom taps.
Nitrocellulose	These are less expensive and the most common air drying coatings for interior service. They are modified with alkyd, acrylic, polyurethane and other resins. They do not have high resistance to chemicals, but they are fast drying and easy to use.	Mainly used for interior applications. They can be used outdoors, but they are usually stripped and replaced at intervals of less than one year.
Cellulose acetate butyrate and propionate	These coatings have a cost comparable with acrylics. They can be used alone or to modify acrylics or alkyds	Could be used for interior or exterior applications.
Polyurethane	Tough and flexible films with good adhesion. They have good abrasion resistance and are resistant to chemicals. Available in both single and two component formulations. Some forms are prone to yellow with time. They darken on exposure to elevated temperatures.	Good for all interior applications.

Polymer	Film Properties	Typical application
Vinyl	Vinyl films are flexible and resistant with goodadhesion. Stabilisation is required.	Very good protection for interior applications. Good for exterior applications provided they are well stabilised.
Silicone	Silicones provide the best potential for coatings which must operate at elevated temperatures. They have excellent resistance up to 250°C. Thin films of these high-cost coatings are sometimes used with protection by a second coat of a more durable, abrasion-resistant lacquer. They require extended curing at high temperatures, and this may cause discolouration of the copper surface.	High temperature applications
Alkyd	Slow drying or baking is required when applying the alkyd coatings. They can be modified with melamine or urea resins. They have a low-cost and are sufficiently durable for exterior applications, although yellowing may occur. Resistance to chemicals is usually good.	Domestic applications where high wear resistance is required.
Soluble fluoro polymer	Will cure to full hardness at ambient temperature or can be stoved to accelerate hardening. Resistant to weathering and ultra-violet light.	Excellent protection with 20 years life expectancy for exterior applications. Suitable for coil coating or on-site application.

Types of Coating

Coatings may be made from any of the polymers listed in Table 1, and the basic properties of the coating are defined by the constituent polymer or polymers, but the properties are also controlled by the way in which the coating is prepared and applied. There are four different types of coating:

- solvent-based coatings, air dried or stoved
- powder coatings
- coatings prepared in sheet form and stuck onto the surface
- radiation cured coatings

Solvent-based coatings

In order to apply a coating in liquid form the film-forming polymer (or mixture of polymers) must be dissolved or dispersed in a suitable liquid. This type of coating is frequently referred to as a "lacquer" [*]. Increasing awareness of the environmental and health hazards associated with volatile organic

[*] The word "lacquer" has an Indian origin (in Sanskrit "laksha" means hundred thousands, derived from the thousands of cochineal insects used to make shellac.) It also conveys the implication of the multiple possibilities that lacquer in itself holds. Because of their moisture resistance lacquers were formerly applied by Egyptians and the Incas to embalm the dead and were connected with the notion of indestructability (ref. 3).[1]

solvents has lead to the development of coatings which have water as the main solvent and many such are now available.

The coating is applied to the surface, the solvent evaporates and the coating film forms. Some coatings may simply be allowed to air-dry, others require gentle heating to speed up the process. Some polymers require stoving to complete a cross-linking reaction.

Air-drying formulations have the advantage that no drying or baking equipment is required, but care must be taken to protect the wet coating from dust which will spoil its appearance. Humidity in the atmosphere may also cause defects. The coatings take some time to reach a fully hard state and whilst they are still soft they are vulnerable to damage.

Stoved coatings are generally harder and more wear resistant than air drying, non cross-linked ones, but care must be taken to ensure that the metal surface does not discolour during the stoving process. It is wise to use as low a temperature and as short a time as possible. In some cases the copper surface catalyses the cross-linking reaction thus enabling lower temperatures or shorter times to be used.

When a coating is being formulated it is generally necessary to include a number of ingredients other than the solvent and the basic film forming polymers. Many different types of additives may be used. They have a wide range of functions such as to improve film properties or to ensure that the coating is more easily applied. All the constituents of a coating solution must be considered for a particular application in order to ensure that optimum performance is obtained.

(i) Solvents

Research shows (ref. 1, 4, 11) that a number of organic solvents are unsuitable for use on copper and copper alloys because they tend to discolour the metal. This discolouration occurs either at the time of application or later even under a non-porous coating, due to the breakdown of residual solvents on exposure to ultra-violet radiation. Ethyl alcohol and isopropyl alcohol have been found to cause staining, but no problems have been experienced with toluene or xylene or their derivatives so these should be used. Due care must, of course, be taken to ensure that health and safety requirements are met during the handling of these solvents.

Fewer hazards are associated with water-based coatings, but not all coating systems can be adapted to aqueous solutions or dispersions and in some cases the desired properties cannot be achieved using a water-based system. Difficulties can also be encountered with surface tension effects preventing the coating from wetting the surface properly, particularly when the coating is applied by spraying.

(ii) Additives for solvent-based coatings

The quality and performance of a coating can often be improved by the addition of compounds other than the film forming polymers. These additives have many different functions. The most commonly found types are: ultra-violet absorbers, antioxidants, chelating agents, plasticisers and levelling agents.

Ultra-violet absorbers

These are organic compounds which are often added to coatings which will be used for exterior applications. They absorb the ultra-violet radiation from sunlight and this prevents darkening and degradation of the coating.

Antioxidants

These are required only in some types of coating. They help to reduce the degradation of coatings during long and severe exposure.

Chelating Agents

Chelating agents are preferentially adsorbed on the surface of the metal and act as an invisible barrier to elements or compounds which might cause corrosion. In this way they protect the metal against oxidants permeating through the coating and continue to protect even after a minor defect has formed in the coating. They may be included as part of a coating formulation or applied as part of a pre-treatment procedure. The most commonly used chelating agent for copper and copper alloys is benzotriazole. This has been found to provide exceptionally good protection (ref. 1).

Plasticisers

Plasticisers improve the flexibility of a film and in some cases improve adhesion. They are added in cases where a particularly tough and resistant film is required.

Levelling Agents

Levelling agents improve the flow properties of coatings thereby ensuring a better surface appearance. They prevent runs and also reduce the likelihood of pinholing and other defects.

Powder Coatings

The film forming polymer (or mixture of polymers) is prepared in the form of a fine powder which is applied to the surface to be coated. The powder particles should generally be in the size range 20-40 microns. The powder-coated surface is subsequently heated which causes the powder particles to soften and flow out to form a continuous surface film. The type of polymer used determines whether the film is described as thermoplastic or thermosetting. In the former, the film hardens on cooling but could be resoftened simply by heating again. In the latter, a chemical reaction takes place during heating and causes the film to harden. A thermosetting film cannot be softened again just by heating to the curing temperature.

Besides the primary film forming polymer (or mixture of polymers) a powder coating generally contains a number of additives, some of which are essential for a satisfactory coating but many are optional and specific for certain end-uses.

(i) Additives for powder coatings

Wetting Additives

These are necessary to allow the coating to flow out and wet the substrate surface.

Air Release Agents

The release of interstitial air as the powder fuses is important, because entrapped air causes pinhole defects in the coating. Air release agents provide a very low viscosity coating on the powder particles as they fuse, and allow all the air to escape.

Catalysts

The curing reaction of the resin in the coating may be accelerated by the use of a catalyst, however care must be taken because the faster reaction always results in a poorer flow-out and an uneven coating may result.

Slip Aids

These improve the surface slip properties of the powder coatings and reduce the marring which occurs where two coated surfaces rub against each other.

Gloss Control Agents

Certain oils or waxes can be added to coatings to cause a very fine "micro-wrinkle" on the surface which reduces the gloss. A similar effect can be achieved in some cases by using a mixture of two resin powders which have different cure rates. Care must be taken to ensure that the surface unevenness is not so great that an "orange peel" effect is seen.

Coatings applied in sheet form

A considerable amount of work has been done to develop and evaluate coatings which are applied in sheet form and glued to the metal surface (ref. 7). They can be applied to copper sheet and coil before the sheet is formed to shape and will deform when the sheet is shaped without decohering or breaking. The most successful film investigated was a polyvinyl fluoride with the trade name Tedlar[R] (registered trademark of Du Pont Co) which was roll-bonded to the metal surface using an adhesive containing benzotriazole as a corrosion inhibitor. The coating was marketed as "Incracoat". The roof of Regents Park Mosque in London is made of gilding metal sheet protected in this way, and its glowing colour is a tribute to the success of the method. Demand for the product has, however, been low and "Incracoat" is no longer commercially available and, as far as is known, no other coating systems of this type for copper and copper alloys have been developed.

Radiation cured coatings

These coatings are applied as liquid monomers or oligomers. They do not contain solvents. After application to the metal surface they are irradiated either by passing them through an electron beam or through a beam of ultra-violet light. The radiation releases catalysts in the coating mixture which initiate the polymerisation reaction forming the solid film. It is essential that there are no radiation shadows on the component so these coatings are normally only used on flat surfaces. They have the outstanding advantage that the process does not require heat, so they can be used on very thin sheets of metal without fear of distortion occurring. They are used for printed circuits, and are applied by roller coating or screen printing.

Methods of Application of Coatings

The most appropriate method of application of a coating will depend on the choice of polymer and the coating type, on the number of items to be coated, and on their shape; and it will, of course, also be influenced by the capital cost of equipment and its availability. Again it must be stressed that advice should be sought from the coating supplier.

It is also vitally important that the coating is correctly applied by the chosen method. Many defects seen in coatings are the result of poor methodology during the coating process. Defects such as the film being too thick or too thin, or the inclusion of dust particles can be eliminated if good practice is ensured. (Further information about defects can be found in 'Defects Which May Occur in Coatings').

Solvent-Based Coatings

Solvent-based coatings may be applied in a number of different ways. Each method has its advantages and disadvantages, and considerations such as the cost of the equipment, the requirements for skilled labour, the amount of coating lost during the process and the necessity for fume control, must be taken into account. Table 2 gives details of the methods available and includes comments on each one.

Table 2 - Typical application methods for solvent-based coatings

Method	**Remarks**
Brushing	A commonly used method for small scale applications. There is efficient use of the coating and capital costs are low, but it is labour intensive. The viscosity of the coating must be carefully controlled. Skill is required to produce films of uniform thickness free from runs.
Dipping	A traditional application method still useful with hand or mechanised techniques. The dip cycle must be slow in order to reduce air entrapment during immersion and to permit good drainage on extraction.
Flow coating	Similar in effect to dipping but the components are flooded with lacquer in an enclosed cabinet. Excess lacquer is recycled.
Roll coating	An automated process for coating strip either on one side or on both sides simultaneously. A high standard of quality is obtained.
Curtain coating	An automated process for coating sheet and strip. The metal passes through a "waterfall" of the coating liquid.
Compressed air spray	A conventional method of application using small, medium or large spray guns and nozzles. 1-2m2/min coverage is obtained. Automation is possible but otherwise skill is needed to obtain a uniform film thickness. Overspray leads to inefficient utilisation of the coating and fume extraction can be a problem.
Airless, or high pressure spray	Can achieve greater efficiency than with conventional compressed air spray. Coverage up to 6m2/min is possible. Inclusion of air bubbles and the occurrence of runs are less frequent.
Electrostatic spray	Electrostatically charged droplets of spray are attracted by charged components. The process gives good, even coverage to complex parts including those with sharp edges. It is easily automated and gives relatively efficient usage of coating mixture.
Electrophoretic coating	An aqueous dispersion of the coating mixture forms the eletrolyte of an electrolytic cell. The component is immersed in the cell and forms one of the electrodes. For coating copper and brass the component must form the cathode. The coating is quickly applied and is of uniform thickness, even over sharp edges and recessed areas, making the process very useful for articles with intricate designs and re-entrant areas. It is particularly suitable for continuous production. The articles do not need to be dried after cleaning. Investment in plant is repaid by low losses of coating mixture, good surface quality, low production costs and minimal fume problems. Skilled maintenance of the plant is essential and care must be taken to avoid contamination of the electrolyte.

Powder Coatings

These may be applied either by electrostatic spraying or dipping.

Electrostatic spray

This is the most usual method for application of powders. The powder particles are charged and directed towards the article to be sprayed which is held at earth potential. The powder is deposited and held onto the surface by the electrostatic force. Subsequent heating melts the powder causing it to flow out to form a continuous film, and finally it sets.

Fluidized bed dipping

The article to be coated is heated and dipped into the fluidized powder which melts onto the surface. Recently, fluidized beds containing electrostatically charged particles have been developed, enabling a cold object to be coated by dipping. The article must then subsequently be heated in order to form a continuous coating.

Surface Preparation

The importance of good surface preparation cannot be emphasised too strongly. It is absolutely essential that the surface is properly cleaned before a coating is applied whatever the chosen method of application. The majority of coating failures in service are due to inadequate surface preparation. In some instances, where a coating is being applied to a plated metal surface, faults may occur in the clear protective coating which stem from inadequate control of the plating operation, even though the plating itself appears to be sound. The performance of an inherently good coating will be severely impaired if it is applied to a dirty surface.

When cleaning and polishing it is important to avoid the use of steel wool and polishing rouges which contain iron. Pads such as "Scotchbrite" are a useful alternative to steel wool.

All traces of polishing compounds, oil, debris and plating solutions must be removed before coating. There are a number of methods which may be used to clean the surface and these are set out and described in Table 3.

After each chemical or electrochemical cleaning operation the articles to be coated must be thoroughly swilled clean in cold water. A cold pre-rinse is often followed by an intermediate hot rinse with the objective of removing the remaining treatment chemicals from the smallest pores, threads and recesses. The last rinse is usually de-ionised or distilled water in order not to leave a residue on the surface after drying. Before coating, the articles are often dried by hot air in an oven or continuous tunnel drier.

Table 3 - Surface Cleaning Techniques

Chemical pretreatment in alkaline solutions	For the cleaning of copper and copper-alloy material, solutions are based on compounds such as trisodium phosphate, sodium metasilicate, sodium hydroxide, and sodium carbonate together with a blend of surfactants, wetting agents and emulsifiers. Generally the cleaning solution contains 2-5% of the salts. An efficient alkaline cleaner must also protect the surface from etching and staining, and must not cause any colour change of the surface. Cleaners containing complexants may allow simultaneous removal of the surface grease contamination and surface oxidation from copper and brass.
Degreasing inorganic solvents	Many organic solvents dissolve oils and fats from metallic surfaces, but they do not always remove the tightly adherent dirt particles nor inorganic products such as polishing compound residues. For this purpose the cleaning process can be accelerated by the use of ultrasonic agitation. When cleaning is to be undertaken manually the surface should be wiped with a white cloth soaked in solvent. This process should be repeated using clean cloths until no trace of discolouration can be seen on the cloth. All organic solvents must, of course, be used only in cleaning plant which prevents the release of the solvent or its vapour into the workplace or the surrounding air space. This requirement has lead to the development of water-based cleaners and degreasers which can be used without elaborate precautions or in fully automated plants.
Electrolytic degreasing in alkaline solutions	Alkaline solutions employed for chemical cleaning can be used for degreasing with an electric potential applied to accelerate the process. The components are subjected to alternating voltages to give a combined anodic/cathodic cycle, the final polarity being cathodic.

Quality Assurance

Quality assurance must include all stages of the coating process from the choice of coating through preparation of the metal surface and application of the coating, to inspection of the final product and its despatch.

This section explains some of the test methods which are used by coating suppliers to determine the properties of coatings and these may be employed by the user to check the finished coating after application to the product. It is certainly advisable that environmental tests are performed on samples before a coating is chosen.

The section also describes some of the defects which may be found in coatings. It is, however, most important to realise that it is not generally possible to repair a defective coating, and in the event of defects being found the manufacturer has no choice but to strip off the coating and start the whole process again. Careful quality control at every stage is, therefore, essential.

Defects which may occur in Coatings

Defects in solvent-based coatings

There are a number of defects which can occur in solvent-based coatings which can be prevented by ensuring optimum surface preparation and application techniques.

Film Thickness

Advice should be sought from the coatings supplier as to the optimum thickness for a particular coating. If the coating layer is very thin interference colours can be seen and this is known as "rainbowing". Too thin a film may also tend to contain pinholes. Several applications of the coating in quick succession may be needed to build up the required thickness. In the case of INCRALAC, for example, several coats should be applied until a thickness of at least 25 microns is built up. If the film is too thick it tends to become obvious and the metal appears to be varnished. Too thick a film can also be uneven, giving a characteristic "orange peel" effect, or there may be runs or "tears" on the surface.

Dust Particles

It is very important to ensure that the coating is applied in a clean atmosphere. Dust and debris can very easily become entrapped on the surface during application of the coating or whilst it is drying. Dust particles mar the appearance and tend to cause localised spots of corrosion on the underlying surface.

Blushing

This is a particularly unsightly defect where a whitish colouration is seen in the film. It is caused by moisture in the film and is seen particularly in air-drying coatings based on organic solvents. Rapid evaporation of the solvent causes cooling of the substrate, and this tends to lead to water condensing on the surface from a humid atmosphere.

Spots

A spotty appearance will almost certainly be due to pinholes or dust in the film which have allowed corrosion to occur on the metal surface.

Poor Adhesion

Any traces of oil or grease or polishing debris on the surface of the metal or in the coating material will tend to prevent the coating from adhering properly to the substrate. Good surface preparation is essential.

Defects in Powder Coatings

Many of the same defects are found in improperly applied powder coatings. Pinholes are frequently the result of entrapped air and an orange peel effect on the surface can be caused either by inadequate flow-out characteristics or by an incorrect choice of resin mixture which contains resins with different cure rates.

Defects in Stoved Coatings - both Solvent-based and Powder

If the stoving schedule is not strictly observed, faults may arise such as a soft film due to insufficient time or too low a temperature; a brittle film, due to too high a temperature or too long a time; discoloration of the metal due to too high a temperature; or (in the case of solvent-based coatings) blistering due to stoving too soon after application of the coating.

Further information about defects in sprayed coatings and how they may be remedied can be found in reference 6.

Testing Coatings

Coating manufacturers supply data sheets describing the properties of their coatings. They use a number of tests, some of which are briefly described in Table 4. In the case of resistance to specific environments the coatings are generally tested using these methods immediately after application and then again after exposure to the environment, and conclusions as to their resistance to the environment are drawn.

In environmental testing, ideally the coatings should be exposed to real environments for long periods of time, but this is rarely practicable and there are many tests devised which simulate severe environments. Examples found in the literature include:

- Weatherometer
- salt-spray cabinet
- 50°C humidity cabinet
- kitchen dishwasher
- artificial perspiration cabinet
- exposure to ultra violet light
- thermal cycling
- solvent resistance

Testing by the coating user

Before the choice of coating is finalised, it is strongly recommended that samples should be tested under conditions as similar as possible to the expected environmental conditions of service. The performance of a coating will be strongly dependant on its situation, and some coatings are more suitable than others for certain substrates. Users can set up their own tests, or they may be able to discuss specific testing with the supplier.

It is also important for the user to perform a number of routine tests after a coating has been applied to ensure that it has been applied correctly and that a good film has formed.

Arguably the most important test is a visual check of the appearance of the coating. This will give an immediate impression of the metal surface condition, the uniformity of the film, the occurrence of defects such as pitting or an "orange peel" effect, or the presence of dust inclusions. It will also determine whether or not the film is fully dry. However, it is also advisable to make a few more quantitative measurements on a routine sampling basis. These might include adhesion, film thickness, hardness, impact resistance and flexibility. For these tests the methods described in Table 4 can be used.

For cured coatings which undergo a crosslinking reaction during stoving, it is also important to check that the crosslinking reaction is fully completed. This can be done by using a solvent resistance test. If the coating is not fully cured, it will quickly dissolve in the solvent.

Tarnishing of the Metal Surface

The tests quoted in Table 4 are essentially tests of the coating itself. Clearly, if the coating cracks or breaks down there will be a tendency for the metal to tarnish in the damaged area. In some cases also the film itself becomes discoloured. However, there must also be some measure of the effectiveness of a good, adherant, clear coating and this is generally done by measuring changes in the colour of the metal surface over a period of time when the sample is exposed. Quantitative measurements of colour and darkness can readily be made, but a subjective decision about the amount of change which is acceptable has to be taken.

Table 4 Commonly used Test Methods for Measuring Physical Properties of Coatings (ref. 2, 3, 9)

Property	Test Method	Remarks
Thickness	Eddy current	Thickness upwards from 0.002mm (10%)
	Differential weighing	More accurate for thin coatings. Results are usually expressed in g/m2 and not converted to actual thickness.
Gloss	Relative intensities of incident and reflected light beams measured	The gloss measured is largely an indication of the reflectivity of the metal surface, although changes in the coating can have an effect
Hardness	Shore scleroscope or pencil hardness	The pencil hardness test involves drawing a pencil lead across the surface. The value quoted is the hardness of pencil which will crumble itself rather than scratch the coating
Impact Resistance	Standard impact test	The degree of starring of the coating is recorded
Abrasion Resistance	There are several standardised tests	Most tests measure loss in weight due to Abrasion
Flexibility	Bending over a conical mandrel	The amount of cracking is recorded
Adhesion	Deep parallel cuts at right angles are made in the film to form a grid of small squares. Adhesive tape is pressed over and then lifted off.	The number of squares remaining is recorded

Future Developments in the Use of Clear Coatings

In the past the major use of clear coatings was for decorative brass and copperware and for architectural decorative features. Increasingly now, as more wear-resistant coatings are being developed, the use is spreading to items requiring greater durability such as bathroom and kitchen fittings.

Copper is enjoying an increasing use for architectural purposes. It is used for roofing, cladding and guttering, not only because of its beauty, but also because of its strength and comparatively light weight when considered against other roofing materials. Architects are using clear coatings to preserve the copper in a particular state of patination rather than allowing the natural green colour to develop.

Prestige buildings are being enhanced with brass railings, ballustrades and banisters, and there is an increasing use of copper alloy extrusions for window and door frames because their appearance is significantly more beautiful than that of competitor materials. Long lasting coatings have been developed for all these applications.

Coatings which can be applied to sheet or strip before forming are also being developed. These coatings are sufficiently adherant and sufficiently plastic to deform with the metal as it is shaped, and no cracking or decohesion occurs. Continuous line production of coated metal can be achieved resulting in considerable cost savings.

Work is also being undertaken to develop coatings for engineering applications, for example automotive radiators. In this particular application the very thin sheets from which the fins are made are eventually susceptible to corrosion induced by salt on the roads. A protective coating must not impair the heat transfer characteristics, and must be applied in such a way as to ensure that all the minute crevices are adequately covered.

There is also a huge field of applications for coatings in the printed circuit industry which has not been discussed at all in this booklet.

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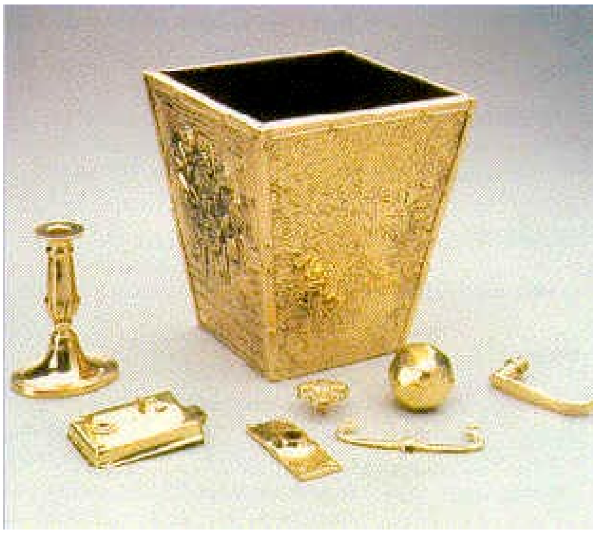
Illustrations



Brass articles protected with durable clear coatings

The ornamental container is coated with ERCALENE which is an air drying lacquer, and the door handles are protected with the stoving system STACRYL. All the items have been coated by a conventional spraying technique. The process can readily be adapted for coating large batches of components or small numbers of items.

(W Canning Materials Ltd)

Articles with complex shapes and re-entrant areas coated by electrophoresis

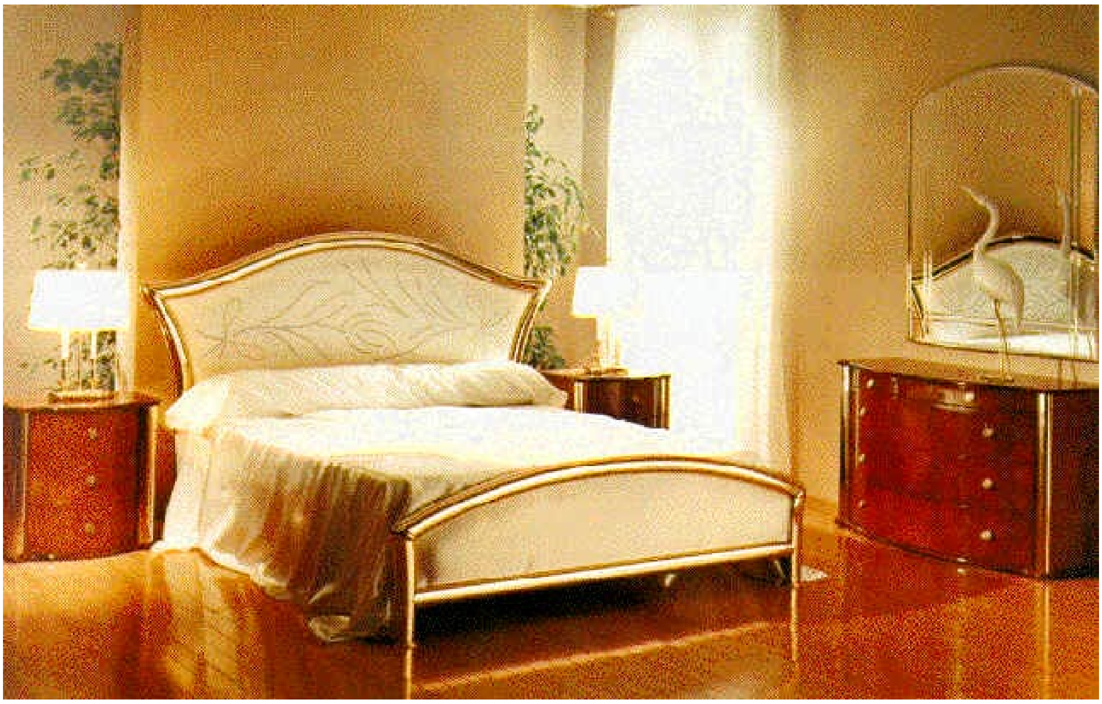
When the article to be coated has re-entrant areas it is difficult to ensure an even coating using a spray technique. An electrophoretically deposited coating overcomes this problem. Cannings ELECTROLAC clear cathodic electrophoretic lacquer is a water-based coating yielding a tough, glossy resilient film. It gives all-over, drip-free coverage to the most complex of shapes.

(W Canning Materials Ltd)

Decorative and functional items protected with CLEARCLAD

(LVH Coatings Ltd)

CLEARCLAD is an electrophoretically deposited, water-based coating system based on an acrylic/urethane resin mixture stoved at 150°C. It is resistant to abrasion and does not degrade in ultra-violet light. The electrophoretic process ensures an even coating on the most intricately shaped components even when the process is automated. The water-based mixture is less hazardous than conventional organic solvent-based coatings, posing few environmental problems. The manufacturer of the door handle has been able to increase the production rate of his components up to four-fold due to the advantages of the CLEARCLAD process.



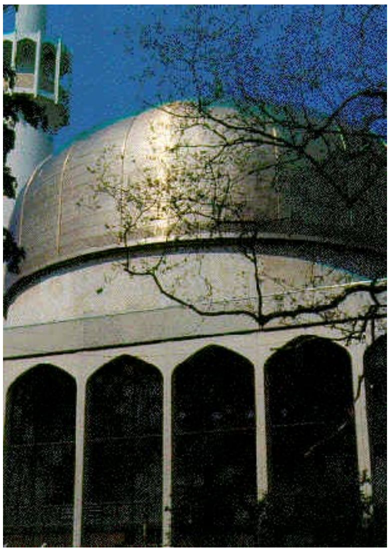
Brass plated furniture protected with ELECTROCLEAR 2000

(OMI-IMASA Ltd)

ELECTROCLEAR 2000, based on an acrylic/amine/urethane mixture, gives hard, durable coatings with an excellent gloss. It can be used either on polished brassware or on articles which have been electroplated with brass. The coating is deposited by electrophoresis from aqueous solution and then stoved for 10 minutes at 160°C.

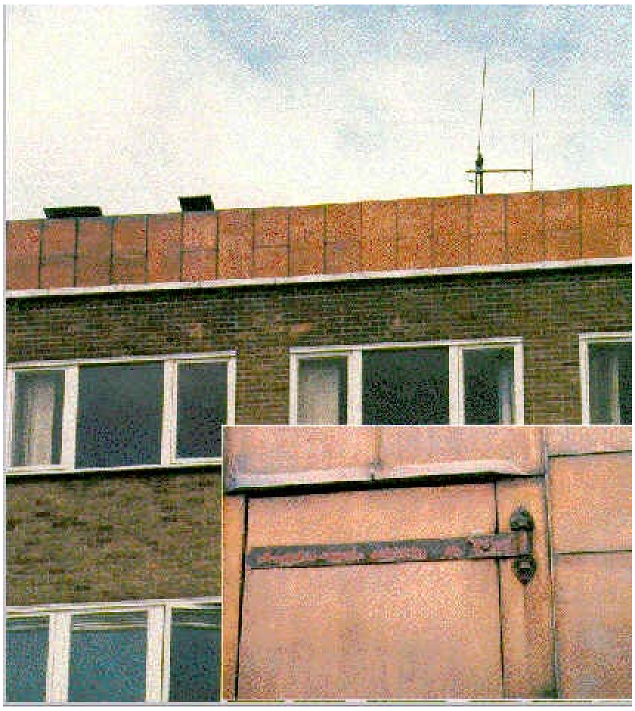
Mexico City Sports Palace

This building was constructed for the 1968 Olympics with a facetted dome, comprising some 21,000m2 of unprotected copper. In most parts of the world it would be expected to weather to an attractive green patina, but in the dry Mexican climate only a patchy grey colour developed after two years. It was therefore decided to restore and preserve the original metallic copper colour by cleaning it and applying INCRALAC.



Regents Park Mosque in London

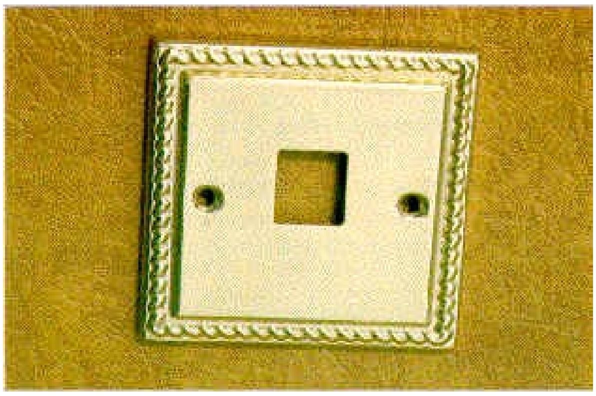
The roof of Regents Park Mosque is made of gilding metal sheet (copper-10% zinc) protected with "INCRACOAT". The sheet film was roll-bonded to the metal using an adhesive containing benzotriazole as a corrosion inhibitor. (Unfortunately "Incracoat" is no longer commercially available.)



Enfield Rolling Mills in North London

This copper roof, situated in an industrial environment, was carefully prepared and coated with several coats of INCRALAC, ensuring that the film was of optimum thickness. The lacquer was expected to last for five years, but the picture shows the roof 20 years after it was coated. No recoating or repair has been undertaken, and it can be seen that the copper is still fully protected (although the steel hinge is looking the worse for wear). This example clearly demonstrates the benefits of scrupulous attention to detail during preparation of the surface and coating application.

(Delta Enfield Metals)



Electrical switchplate made of polished brass, protected with a polyester powder coating

This switchplate, designed to withstand repeated handling, is protected with a thermosetting polyester powder coating. The curing schedule is ten minutes at a metal temperature of 170°C. The coating shows excellent resistance to abrasion, impact, humidity and weathering.

(ICI Powders (UK) Ltd)

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