

Electroplating

A guide for designers and engineers

Prepared for the Committee for the Promotion of Electroplating by Joseph Edwards

The Committee for the Promotion of Electroplating is sponsored by the Institute of Metal Finishing, the British Metal Finishing Suppliers Association and the Metal Finishing Association, and comprises representatives of these bodies, and of Inco Europe Limited and the Zinc Development Association.

For further information please refer to:

The Committee for the Promotion of Electroplating
c/o The Institute of Metal Finishing, Exeter House, 48 Holloway Head, Birmingham
B11NQ Telephone 021-622 7387

Foreword

The UK plating industry - in common with that of most other countries - is highly fragmented, and therefore lacks the concerted marketing and industry development so effectively practiced by the paint and galvanizing industries.

This Guide is a further step by the Committee for the Promotion of Electroplating in bridging the information gap between the plating industry and the engineering and production management of the manufacturing industry.

Today, electrodeposition technology offers the engineer the capability of providing specific surface properties, such as wear resistance, lubricity, hardness, solderability, electrical conductivity, corrosion resistance onto constructional metals or plastics which in turn satisfy the need for particular mechanical design needs. In these applications, the deposition of surface films is almost always cost effective and highly efficient; technology well suited to society's thrust for energy and material conservation.

CPE hopes that this Guide will enable the discerning engineer to think in broader design concepts than perhaps hitherto, and that through electrodeposition technology, industry can more effectively accept the challenge of the eighties.

David Hemsley
CHAIRMAN
Committee for the Promotion of Electroplating.

Committee Members

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J.D.C. Hemsley, Chairman	British Metal Finishing Suppliers Association
J.E. Thomason, Treasurer	British Metal Finishing Suppliers Association
E.P. Arnall	Inca Europe Limited
M.J. Ashton	Metal Finishing Association
J. M.Bennett	Metal Finishing Association.
A.R. Poeton	Metal Finishing Association
R. H. Pinner	Institute of Metal Finishing
F. C. Porter	Zinc Development Association
P.G.L. Vivian	Institute of Metal Finishing

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Introduction

Surfaces are not always given their proper due. In the design of manufactured goods and engineering components, they may come low in the order of priority. To allow this to happen could be a serious miscalculation.

The surface of any article is the interface with its surroundings. It determines its response to chemical and physical circumstances, its resistance to corrosion and tarnishing, its tolerance of impact and abrasion, its frictional and contact behaviour. It is what the consumer sees and touches, and so it contributes positively, or otherwise, to his satisfaction, both when the article is new and when it is well into its expected lifespan.

Unless the immediate environment is controlled, there are surprisingly few applications in which homogenous materials give an adequate account of themselves. The obvious resort is to coatings, which enable the bulk properties of one material to be combined with the surface properties of another.

Many types of coating are employed. Organic finishes account for the greatest coverage. Conversion coating procedures are widely used: one, phosphating, is mainly a preparative treatment for painting, while another, anodising, is a finishing process in its own right. Metal coatings are applied by hot dipping, spraying, cladding, chemical and physical deposition methods. There is currently a great deal of interest in advanced physical techniques, such as ion plating and ion implantation, and these are likely to make great headway in specialized applications. But the group of processes offering the greatest diversity of properties and applications is that with which this guide is concerned: electroplating.

Electroplating is well established but not very well known. Unlike painting (some kinds, anyway), it is hardly a domestic art. Its apparent difficulty and complexity may obstruct its wider utilization. The object of this guide is to penetrate the aura of mystery surrounding electroplating, as a step towards procuring its full industrial potential. It is directed principally at those concerned in the design and specification of manufactured metal products.

The sequence followed is to summarise existing applications as an illustration of the usefulness of electroplated coatings; to outline the fundamentals of electroplating; to review the factors to be borne in mind in designing articles to be electroplated and the relevant characteristics of individual basis materials and plating processes; and to give some guidance on commercial matters. A list is included of useful sources of further information.

Grateful acknowledgement is made to all the many people who assisted in the preparation and production of this guide.

Important Properties of Plated Coatings

	Cadmium	Chromium	Copper	Copper Alloys	Gold & its alloys	Lead	Lead-tin	Nickel (electrolytic)	Nickel (electroless)	Ni & Co composites	Pt group metals	Silver	Tin	Tin alloys	Zinc	Typical applications
Abrasion resistance		X							X	X	X					Hydraulic power. Machinery & tools
Conductivity			X	X	X							X				Electrical and Electronic equipment
Corrosion resistance	X	X			X	X	X	X	X		X		X	X	X	Automotive engineering - Domestic appliances - Building Oil & chemical plant
Decorative appearance		X		X	X			X	X		X	X	X	X		Jewellery - Consumer durables - Furniture - Medical equipment - Plumbing - Shopfitting tableware
Contact resistance					X						X					Electrical connectors
Non stick resistance		X														Plastic moulding materials
Oil retentiveness		X														Hydraulics equipment
Rubber adhesion				X												Tyre manufacture
Softness & lubricity	X					X	X					X	X			Bearings - Rubbing surfaces
Solderability	X		X	X	X	X	X	X	X				X	X		Manufacturing industry - Repair work - Electrical connections
Rebuilding worn parts		X	X					X								Mechanical engineering industries

Historical note

Shortly after Volta had invented the first battery, the so-called voltaic pile, one of his colleagues, Brugnatelli, used it as a source of current to electrodeposit gold on two silver medals, thus becoming the world's first electroplater. The year was 1803. Not unusually, the innovation was slow to develop. Only a few plated articles survive from the early years of the nineteenth century, but there is a famous one in the Royal Collection at Windsor Castle: a gilt silver cup, made by Storr in 1814 and known as the Galvanic Goblet.

A further quarter-century passed before the Elkington cousins established the electroplating of silver and gold on an industrial scale in 1839. Meanwhile, Faraday had defined the first and second laws of electrolysis in 1833-4 and Daniell, in 1836, had developed the cell named after him, a much more reliable source of current than had existed before. The Elkingtons installed Daniell cells in their first plating shop; however, when Woolrich's Electro-magnetic Machine (based on Faraday's discovery of electro-magnetic induction) became available in 1845, they were quick to take it up.

Nickel plating was first performed by Bird in 1837, but it was not until 1868 that Adams, having made many improvements, was able to put the process into commercial operation. Zinc and copper electrodeposition were developed over the same period. There was a long gap, however, before chromium plating emerged, by a tortuous process in which many people were involved (Sargent, Fink, Schwartz, Udy and Liebreich), during the decade of the 1920' s.

1. The uses of electroplating

Decoration

Chrome plate

The most familiar of all electroplated coatings is chrome plate, not as common as it used to be on cars, but usual still on bicycles, domestic goods and fittings, hospital equipment, tubular furniture and wire goods, as well as many fasteners and other small items. (Figures 1 and 2.) The surface is usually bright, but satin and black finishes are also available.

In spite of the name, chrome plate is mainly a nickel coating, sometimes on a copper undercoat, with only a thin top coat of chromium. Whether it is bright, satin or matt depends on the surface texture of the nickel, but black chrome-requires an additional process. If produced to the appropriate specification, its decorative appearance is very long-lasting in most conditions of use. This is because chromium is hard and abrasion resistant and, although inherently a base metal, rapidly forms a tenacious, impermeable and self-healing oxide film, which causes it to behave in a noble manner in ordinary atmospheric conditions. Thus it is highly resistant to tarnish and corrosion.

The metal is brittle, however, and is deposited in a stressed condition, so that cracking occurs when the thickness exceeds one or two micrometres (μm)*, the precise limiting thickness depending on the plating conditions. At thicknesses below about $0.5 \mu\text{m}$, the coating is porous. Consequently, as the thickness varies significantly over a shaped article, it is difficult to achieve a chromium coating that is entirely free from discontinuities. Fortunately, the underlying nickel is resistant to corrosion and able to delay penetration to the basis metal without giving rise to unsightly corrosion product.

In severe environments, however, with only a few widely spaced discontinuities in the chromium, attack on the small areas of nickel exposed can be very rapid, so that

Figure 1



Figure 2



* $25 \mu\text{m} = 1$ thousands of an inch.

penetration to the base can occur within a short time.

The solution to this problem was found about 20 years ago. Simple but paradoxical, it is to create a high density of very small discontinuities in the chromium. In aggressive environments attack occurs at all these sites, but the wide spread of the total corrosion current brings about a drastic reduction in the rate of penetration. Very long life can thus be assured, with only gradual loss of lustre resulting from the widely dispersed superficial corrosion. The very tiny discontinuities deliberately produced in the chromium may be either cracks or pores. Depending on the particular processes employed the top coats of microcracked and microporous chromium have minimum thicknesses in the range 0.3 - 0.8 μm .

Benefit is also gained by using nickel deposits that are more resistant to penetration than single-layer bright-deposited coatings, for example: dull or semi-bright deposits requiring polishing to give full brightness, or double-layer coatings comprising a semi-bright lower and a bright upper layer. In BS 1224 these three types are designated: b, p and d, respectively. The types of chromium are distinguished as follows: r for regular (or conventional), mc for microcracked and mp for microporous.

The British Standard recommends 20 μm of any of these nickel deposits plus any of the chromium deposits for steel articles intended for moderately severe indoor conditions, e.g. in kitchens and bathrooms. For service outdoors in exceptionally severe conditions, however, it recommends one of the combinations shown in Table 1 (the standard gives equivalent guidance also for coatings on zinc alloy, copper or copper alloys and aluminium or aluminium alloys).

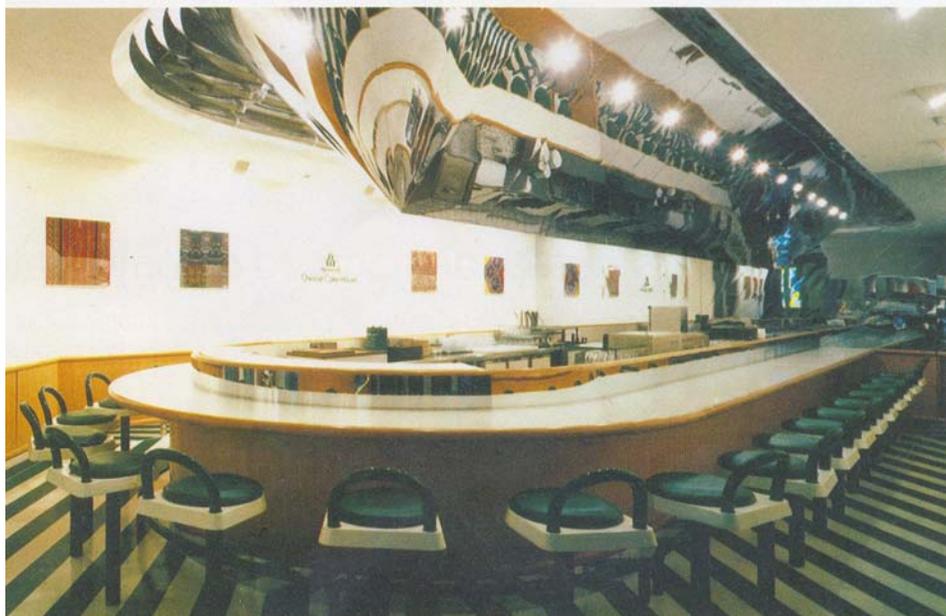
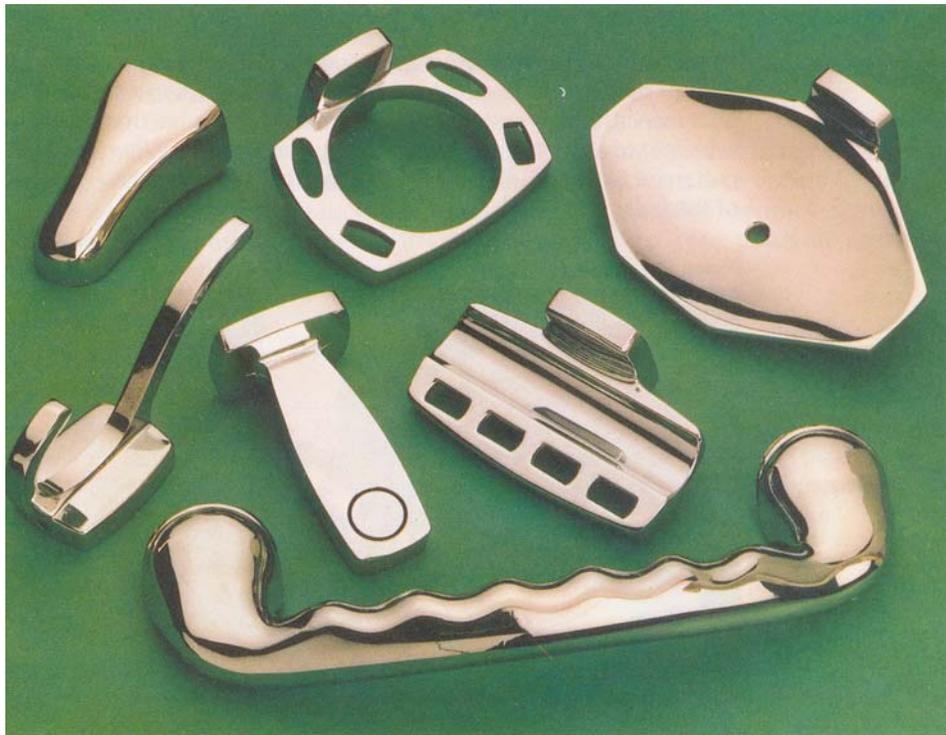
Table 1. Nickel plus chromium coatings on steel suitable for severely corrosive outdoor conditions.

Ni	Cr
40 μmp	r
30 μmp	mc
30 μmp	mp
40 μmd	r
30 μmd	mc
30 μmd	mp

Note that for these service conditions single layer bright nickel is excluded and regular chromium requires a thicker undercoat. Choosing the correct combination guarantees the maintenance of a bright appearance for a very long time, even in severe environments.

Chrome plate can be applied to plastics as well as to metallic materials. (Figure 3.) The polymer most commonly used is ABS (acrylonitrile-butadiene-styrene), but others can be successfully plated, for example, polypropylene, polyphenylene oxide and polyarylethers. There is a British Standard specification (BS 4601) for electroplated coatings of nickel plus chromium on plastics material. The pretreatment of plastics for

Figure 3



plating is rather complicated, but good results are consistently obtained by the platers who specialize in this kind of work.

It has been shown that the decorative appeal of chrome plating can be enhanced by texture patterning. The parts of the surface that are to retain full brightness are shielded by a stencil, which need be nothing more substantial than plastic tape, while the article is bombarded by a water slurry of tiny glass beads. When the stencil is removed, the pattern is revealed. (Figure 4.) The treatment has no adverse effect on the durability of the finish.

Figure 4



Substitutes for standard chrome plate

For economy's sake, nickel-iron alloy deposits are sometimes used instead of nickel as the undercoat for chromium. These are entirely satisfactory indoors and can be used for several outdoor applications.

Nickel or nickel-iron alloy coatings are also used without chromium top coats, especially on hand tools. On such articles, handling prevents tarnish developing, and resistance to wear may be as important as resistance to corrosion; initial appearance is an important sales factor, however.

Black nickel finishes can also be obtained but they have no great durability and so require a protective lacquer coating.

A tin-cobalt alloy electrodeposit' containing about 20% cobalt can be used as an alternative to chromium on top of nickel. It looks rather different from chromium, but behaves equally well, and possesses process advantages that enable it to be used where chromium plating is not practicable (e.g. bulk plating of small items is feasible in conventional barrels).

Another tin alloy, tin-nickel, containing 35% nickel, is highly resistant to tarnish and corrosion, and is used by itself as a decorative and durable finish on a variety of goods. It has a bright, metallic appearance with a pink tinge. The coating is so noble that rapid attack on the basis metal occurs in corrosive conditions, if any pores are present; consequently, it is not much used in outdoor applications.

Copper and its alloys

Thin electrodeposits of copper, bronze and especially brass are used for finishing a variety of household articles. The coatings may be bright or satin in appearance, or they may be coloured, or bronzed, by one or other of many available dip treatments and possibly high-lighted by selective polishing; they are often applied over an undercoat of nickel and almost invariably protected by a transparent lacquer. (*Figure 5*)

Figure 5



Precious metals

Silver was the first electrodeposited metal to be used for decorative purposes. It is still to be seen on personal and domestic articles and musical instruments. Stainless steel has made inroads into its use as the dominant finish for cutlery and tableware, but the application survives. BS 4290 advocates minimum thicknesses of 10 to 50 μm on cutlery and flat ware and 5 to 25 μm on hollow ware. Nickel silver, an alloy of copper, nickel and zinc, is the preferred basis metal. On high quality cutlery, special techniques are employed to ensure that the greatest deposit thicknesses are applied to areas subject to most wear. Even articles made of solid silver are sometimes silver plated to improve their appearance.

Polished silver is a superb finish but it is rapidly tarnished by sulphur compounds. The only fully effective preventative is a coating of rhodium about 0.3 μm thick; this is highly resistant to both abrasion and tarnish, but it is slightly darker than silver and expensive. Lacquer coatings are therefore more often used, or sometimes thin films of tin or silica.

Gold plating is seen on jewellery, watches, some hollow ware and musical instruments, and quite frequently on bathroom fittings. An undercoat of bright nickel is often used. The minimum coating thicknesses specified in BS 4292 range from 0.5 to 2 μm or, for special applications, from 4 to 16 μm . Gold alloy coatings, generally harder than pure gold, are usually employed; these can be produced in various colours, so-called 'green' (with silver), 'red' (with copper) and 'rose' (with both silver and copper). (*Figure 6.*)

Others

Modern bright zinc finishes are attractive in appearance and so are used in some applications as much for decoration as protection. Lacquered, they compete with chrome plate on supermarket trolleys and baskets. (*Figure 7.*) Tin is another metal that can be deposited in a bright form. On the whole, however, it seems best to give full consideration to both zinc and tin under the heading of corrosion resistance.

The point is made, however, that most, perhaps all, electroplated coatings tend to have a good appearance, certainly as produced. The visual impression is not a negligible factor, even when the coating is applied primarily for another purpose. In manufacturing operations it has often been noted that a superior finish on components induces greater care and cleanliness on the part of assembly workers. The consumer also likes a trim, professional appearance even on items that are not normally on display, but which he will see from time to time, such as those under the bonnet of his car.





Corrosion protection

Zinc

Just as appearance is nearly always a factor in choosing electroplating, so is resistance to and protection against corrosion, whatever other surface properties are required. There is no doubt, however, that sometimes corrosion resistance is the prime requirement.

A distinction can be made between those coatings that shield the substrate from the environment and those that exert sacrificial cathodic protection. It is worth bearing in mind, however, that all continuous metal coatings constitute a barrier, and that those capable of sacrificial protection do not primarily act in this way, but must themselves have a natural resistance to corrosion if they are to have an adequate life.

These considerations can be applied most particularly to zinc. Coatings of this metal are, in fact, highly resistant to corrosion by the atmosphere and most natural waters provided they are not acidic or highly alkaline. The resistance is due to a compact layer, mainly of oxide and hydroxide, which soon forms on a zinc surface. Careful rinsing and drying after plating helps ensure the protectiveness of this layer, but a surer way is to apply a chromate passivation treatment, which provides an effective safeguard against 'white rusting' (formation of a voluminous corrosion product, mainly basic carbonate) in very damp conditions.

Several types of passivation treatment can be specified, giving films of varying appearance and corrosion resistance. The following, for example, are recognized in the international standard, ISO 4520, the times given in parentheses being those to the initial formation of white rust in a neutral salt spray test, such as that described in BS 5466: Part 1:

- A. Clear - prevents staining on handling, while preserving bright appearance (10 hours).
- B. Bleached - slightly iridescent or dull (16 hours).
- C. Full- yellow or iridescent (72 hours).
- D. Olive drab -less attractive opaque brown/green (96 hours).

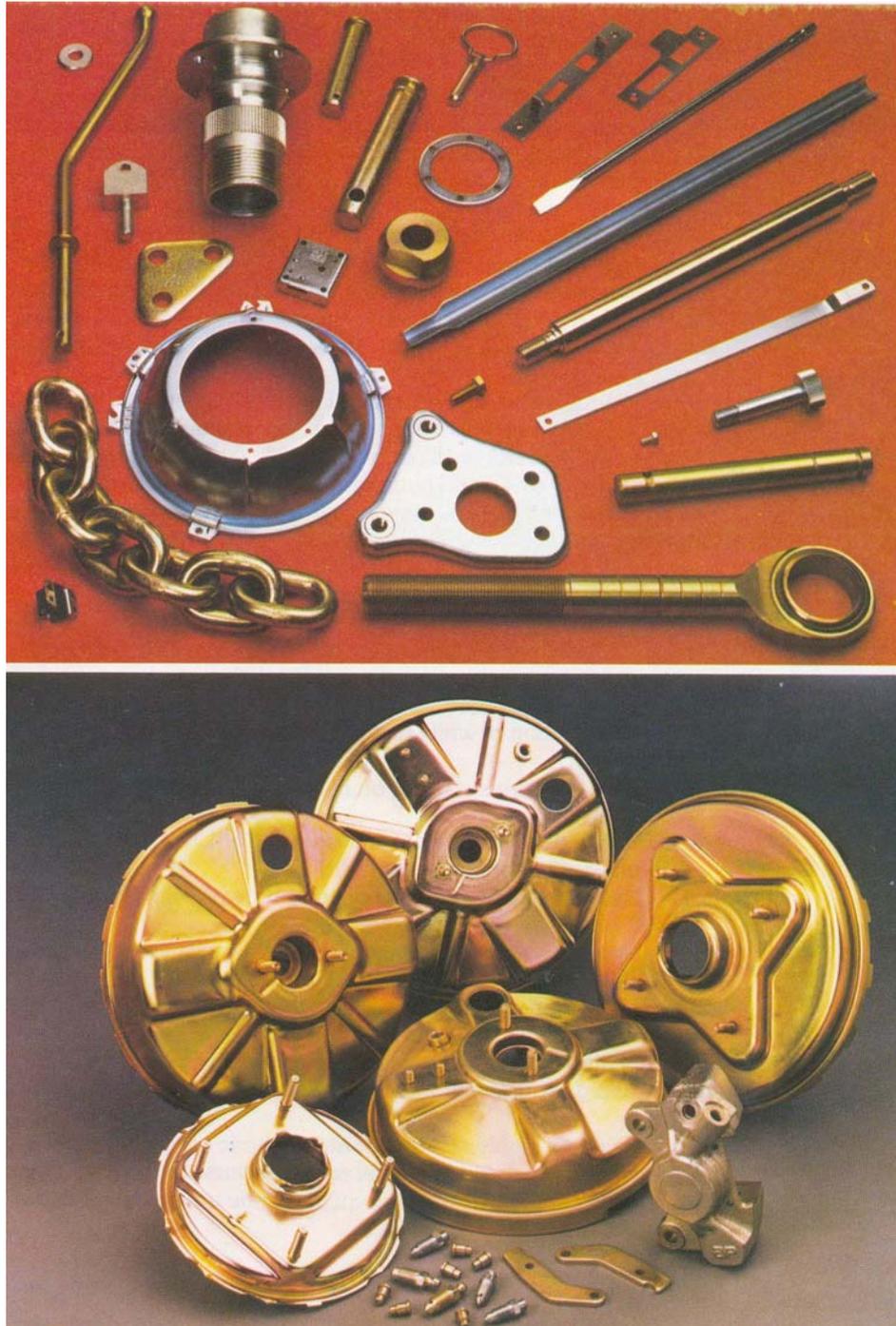
The clear and bleached film can be coloured by various dyes, if wished. (*Figure 8.*)

Chromated or phosphated zinc is sometimes used as an undercoat for paint.

Electroplating is generally the best way of applying coatings of zinc up to 25 μm thick, but hot-dip galvanizing or metal spraying is preferred for thicker coatings.

Although zinc is highly resistant to atmospheric corrosion, it suffers more rapid attack in heavily contaminated industrial areas, because of the acidity, of condensate formed under these conditions. Salt present in marine environments also increases the rate of attack, but not to the same extent.

Figure 8



The service life of a zinc coating is very much a function of its thickness, as it is eventually corroded away. BS 1706 recommends a minimum 5 μm for dry interiors and 25 μm for marine atmospheres and tropical conditions of high humidity.

The ability of zinc to provide sacrificial protection to a substrate such as iron or steel comes into play if the coating is incomplete or is damaged during assembly or service. Such protection is vital in some circumstances. Under moist conditions, however, unless the gap is plugged with corrosion product, exposure of the basis metal will locally accelerate dissolution of the zinc. An increasing area of basis metal will be exposed. Inevitably, at some point in time, the protective action of the zinc will cease to extend as far as the middle of this bare area, and the substrate itself will be subject to corrosion. It is good practice therefore to exploit sacrificial protection as a secondary, rather than a primary, line of defence.

There is considerable interest at present in the possibility of increasing the corrosion resistance of zinc coatings by making alloying additions. About 10% of nickel incorporated in the zinc plate lowers the corrosion rate considerably, and a few manufacturers are marketing steel strip coated with such an alloy as a competitor to the well established electrogalvanized, i.e. zinc plated, material. Sacrificial protection ceases if the nickel content is raised much above this level. Other alloying constituents have been found to increase the corrosion resistance of zinc, e.g. cobalt.

Cadmium

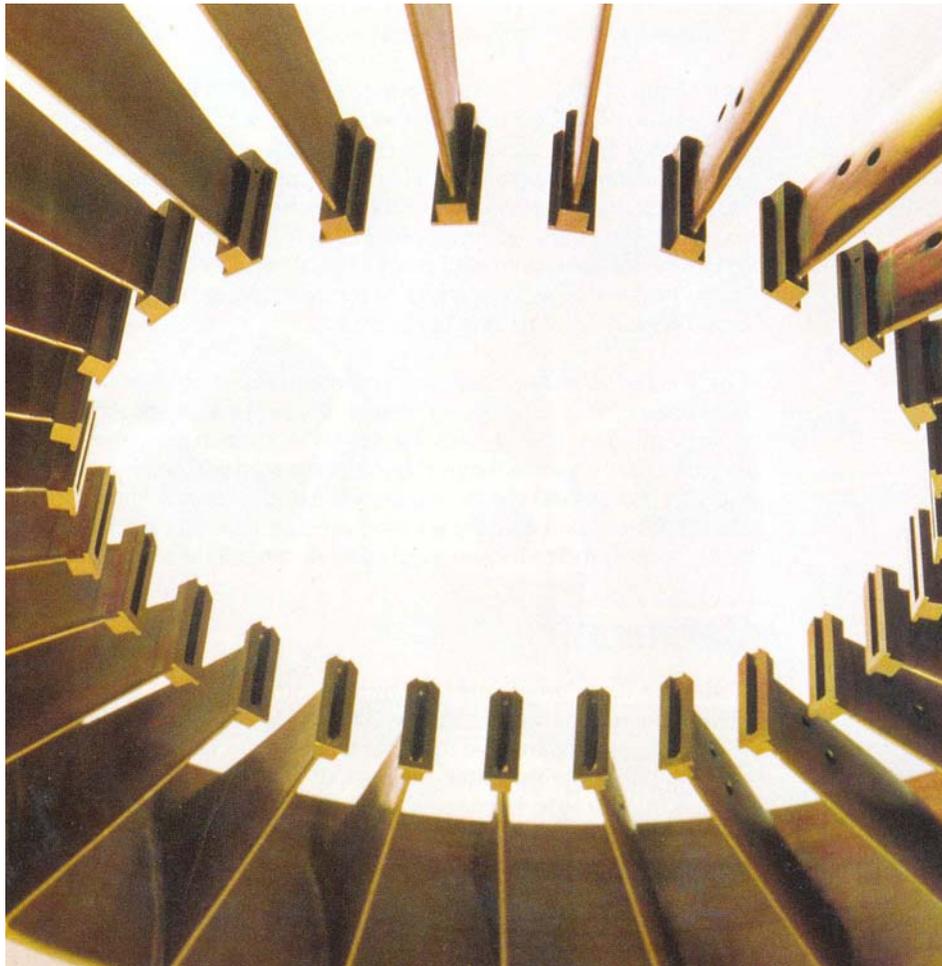
Cadmium has a great deal in common with zinc, but it is much more expensive, and the metal and its compounds are highly toxic if inhaled or ingested. It is whiter and somewhat more attractive in appearance than zinc. (*Figure 9.*) It withstands a marine environment notably better, because of the greater insolubility of its basic chloride, but it is inferior in industrial atmospheres. Although its corrosion potential is not as negative as that of zinc, it can cathodically protect steel. It is less prone to form bulky corrosion products, which could for example interfere with the operation of mechanisms, It is preferred in the electronics industry because it has lower contact resistance and is easier to solder. Where the application warrants the extra cost, cadmium is favoured on threaded components, as it has less tendency to stick and tightening to a prescribed tension is thus easier.

Passivation treatments can be applied to cadmium in the same way as to zinc, and give similar benefits.

In spite of the hazards and the cost, cadmium plating is often specified, especially by the defence and aviation industries, and is still carried out on a reasonably large scale.

BS 1706 advocates a range of coating thicknesses between 5 and 10 μm for varying conditions of service. The upper end of this range is much lower than is specified for zinc. The standard warns, however, that the protection afforded by cadmium and zinc coatings of the same class is not equal. Table 2 shows the time to the first appearance of rust in various environments on steel plated with 25 μm of zinc or cadmium, as-plated or after passivation

Figure 9

Table 2. Rusting of steel plated with 25 μm Zn or Cd

Conditions of exposure	Years to appearance of rust			
	Zinc		Cadmium	
	as - plated	passivated	as - plated	passivated
Industrial	2.1	2.6	0.9	1.5
Urban	3.0	3.8	2.1	3.0
Rural	4.0	4.8	7.5	15.0
Marine	2.1	2.1	1.9	4.0

Tin and tin alloys

Tin is used mainly in the manufacture of tinfoil. When made by the electrolytic rather than the now much rarer hot-dip process, this usually has a coating thickness in the range 0.4 -2 μm . The material is bright, easily soldered, readily formed and decorated. Its corrosion behaviour is important but varies according to circumstances. Inside sealed food cans, tin tends to corrode in preference to any steel that may be exposed; this is important, as tin, in contrast to iron, has little adverse effect on flavour. The amount dissolved is usually small as the reaction rate rapidly decreases, and there is normally a coating of lacquer on top of the tin. In other environments tin tends to be cathodic to steel, which therefore corrodes through the pores in the thin tinfoil coatings if the surface is wet.

Tin coatings are often applied to vessels and equipment used in the food industry. (Figure 10.) In this application it is essential to maintain a complete cover of tin to resist corrosion and abrasion. BS 1872 specifies a minimum thickness of 30 μm for this purpose on both ferrous and copper-base materials.

Electrodeposited coatings of tin-zinc alloy, containing about 25% of zinc, offer better protection than zinc coatings in some environments and are preferred, for example, on hydraulic components. They are used on electrical components also, because of their good solderability compared with that of zinc.

Figure10



Silver

Silver has a high resistance to many chemicals and foodstuffs, and so is used to coat equipment, vessels, pipes, etc. used in the chemicals and food processing industries. Coatings of 100 μm or more in thickness are met with in this application, in spite of the high cost of silver.

*Prince of Wales Coronet, produced by electroforming technology.
(Courtesy of The Worshipful Company of Goldsmiths)*



Engineering applications

Hard surfaces

Ever since the first world war, electroplating methods have been used to build up and restore damaged, worn and over-machined components. The practice persists, but with the passage of time the methods employed have increasingly formed part of the initial design concept for various engineering parts. The best combination of bulk and surface properties is thus achieved, and deterioration due to wear and corrosion curbed.

Nickel and chromium are the main metals employed, on basis metals of carbon or alloy steel, cast iron and aluminium alloys. Copper is used in certain circumstances.

In engineering applications, chromium plate is customarily described as hard chromium. Thickness up to 150 μ m is generally recommended, although thicker coatings are possible. Except in regard to thickness, hard chromium is not significantly different from a deposit applied for decorative purposes. It is genuinely hard, 850 -1000 HV, it has a very high melting point, 1850 $^{\circ}$ C, a low coefficient of friction and high resistance to galling. Coatings thicker than 75 -100 μ m require grinding and polishing to achieve the specified dimensions. By the use of special techniques a highly reflecting surface can be obtained, with something approaching optical perfection.

(Figure 11.)

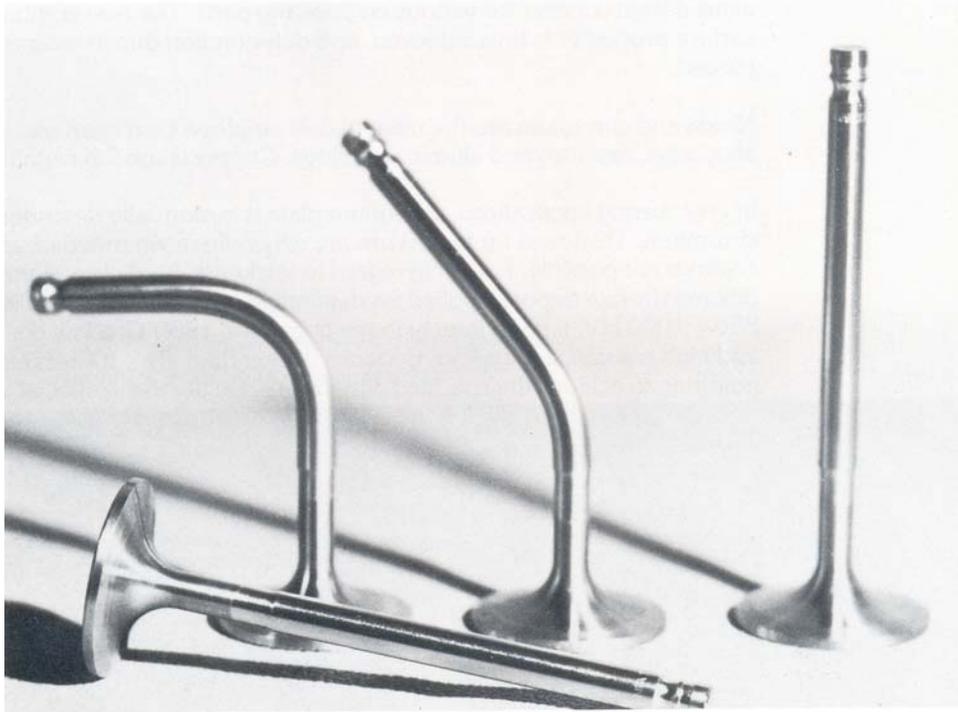
Figure 11



An application that well illustrates the benefits of hard chromium is on car engine exhaust valves. These are subjected to heavy loads and operate, very many times per second, at temperatures up to about 750°C. To survive these conditions they are made of special steel and their stems are coated with 5 -8 / μm chromium.

(Figure 12.)

Figure 12



Other well established applications are on gauges, cutting tools, shafts, gears, rams, moulds and dies. On components such as cylinder liners, piston rings, etc., chromium coatings may be deliberately made porous by chemical or electrochemical etching to make them able to retain lubricants.

Much use is made also of nickel coatings on engineering components. Conventionally described as heavy nickel deposits, they can be extremely thick: up to 500 μm on new parts and even up to 5 or 6 mm on salvaged components. These coatings can be finished either by grinding or machining. Their hardness is much less than that of chromium, about 200 HV being usual; the considerably harder deposits (up to 600 HV) produced from solutions containing organic addition agents are generally unsuitable for engineering use, although it is possible to modify the bath composition without adding organic substances and increase the hardness to about 350 HV. Furthermore, in contrast to chromium, nickel tends to gall when rubbed against steel or another like surface. Consequently, it is mainly used on parts requiring enhanced corrosion resistance, or as an undercoat for hard chromium.

Hardness as high as 500 HV can be achieved in nickel-cobalt alloy electrodeposits at cobalt contents around 35%.

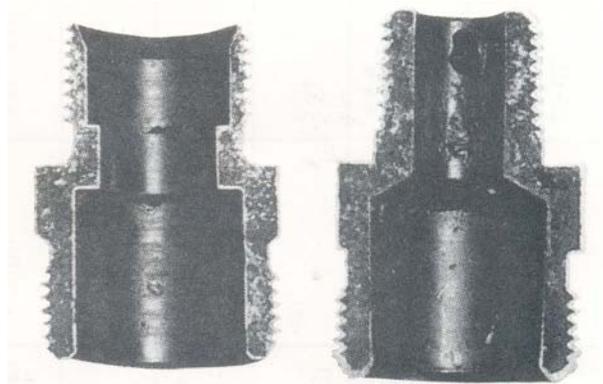
Over the last two or three decades there has been a steady increase, recently at a rate of about 15% per annum, in the use made of electroless nickel, mainly in engineering applications. No supply of electric current is needed to produce electroless nickel coatings; instead, nickel ions in solution are reduced to metal by the action of a chemical reducing agent. The nickel surface itself acts as a catalyst for this reaction, so a more fully descriptive name for the process is 'autocatalytic chemical reduction'; 'electroless' is the name by which it was first known, however, and it has stuck.

The reducing agent most commonly used is sodium hypophosphite, and a variable amount of phosphorus (around 10%) is co-deposited with the nickel. Boron compounds, such as sodium borohydride, are sometimes used instead, in which case the coatings produced contain about 4% boron, and still lower boron contents are attainable using one of the latest processes. All these reducing agents are costly, and the baths have a relatively short life before they must be renewed; hence the process is dearer than electroplating.

It has one major advantage, however: an ability to coat the entire surface of the most complex shaped articles with a nickel-alloy layer of almost uniform thickness.

(*Figure 13.*) Almost as important is the improvement in mechanical properties compared with nickel electrodeposits. The nickel-phosphorus alloy, for example, has a hardness of 500 HV as deposited and this can be increased to about 1000 HV by heat treatment at 400°C. Abrasion resistance is higher, and even the galling resistance is improved, especially in contact with aluminium, titanium or stainless steel. The corrosion resistance appears to be better in some environments than that of electrodeposited nickel but worse in others.

Figure 13



Autocatalytic nickel plating of the sectionalised component on the left shows a uniform deposit, even in the bore.

On the right, conventional electrolytic nickel plating has caused an uneven deposit, with build-up particularly on the shoulders and minimal deposit in the bore.

Electroless nickel coatings are applied to many kinds of components used in the nuclear power and chemical industries, as well as to moulds, tools, mechanisms, etc. it is unusual for the coating thickness to exceed 100 μm . A recent development is the use of a barrel, bulk plating method to apply electroless nickel coatings of only a few micrometres thickness to the steel cans of primary alkaline manganese batteries.

Thick coatings of copper have various applications. They are deposited on steel wire to give high strength electric cables, on stainless steel cooking vessels to improve heat distribution and on electroformed nickel shells to confer higher strength and thermal conductivity. Worn and over machined parts are sometimes built up with copper, which is especially useful in conferring protection against fretting corrosion.

Table 3 summarises the properties and major uses of copper, nickel and chromium coatings on engineering components.

Table 3 Wear and corrosion resistant finishes for engineering components.

Code	***** excellent	**** very good	*** medium	** poor	* very poor	
	Copper	Electroplated Nickel (EPN)	Electroless Nickel (ELN)	Chromium	ELN + chromium	EPN + chromium
Thickness range (µm)	12.5 - 500	12.5 - 500	12.5 - 100	12.5 - 500	12.5 - 100 + 25 - 50	12.5 - 500 + 25 - 50
Corrosion resistance	*	****	***	**	****	****
Wear Hardness (HV)	60 - 150	200 - 300	450 - 500 900 - 1000 after heat treatment	850 - 950	850 - 950	850 - 950
2. Low friction anti - stick	**	**	***	****	****	****
3. Resistance to impact	***	****	***	***	***	****
Maximum working temperature (°C)	50	650	550	650	550	650
Covering complex shapes	***	***	****	*	****	***
Non - toxicity	*****	****	****	****	****	****
Cost for given thickness	£	£ £	£ £ £ £	£ £ £	£ £ £ £ £	£ £ £ £
Specifications	None	BS 4758	DEF 03 - 5	BS 4641	DEF 03 - 5 BS 4641	BS 4758 BS 4641
Typical applications	Build up; lubricant in forming; heat sink; selective case hardening.	Build up; under or instead of Cr in corrosive conditions; printing surfaces.	PVC moulding tools & dies; moving parts in process industries; glass, rubber moulds.	Moulds, tools, valves, rams, pistons, shafts, gauges, dies, saw blades.	High temp. anti-seize bolting; ball valves, shafts.	Marine crane rams and hydraulics; mine roof supports; print rolls.

Grinding needed over 200 µm

Ni at least 50 µm for corrosive environments

Guide to abrasive wear resistance

Guide to adhesive wear resistance

Thin coats and soft substrates prone to damage

Short times at high temp possible

Depends also on shape, size

Soft bearing surfaces

Electrodeposited overlays are applied to the linings of plain bearings used in most kinds of engine. They improve corrosion resistance and provide a cushion that can embed foreign particles and accommodate minor misalignments. The coatings used are mainly lead-tin, lead-tin-copper or lead-indium; there is almost always a thin intermediate layer of nickel.

Miscellaneous

As noted in Table 3, copper coatings (usually 10 - 40 μm thick) are employed as a stop-off in the selective nitriding or carburizing of steel. An important application of brass plating is to obtain adhesion of rubber to metal. In contrast, chromium is plated onto moulds in which rubber articles are made to prevent the rubber sticking. Silver coatings applied to the mating surfaces of stainless steel aero-engine casings stop spontaneous welding in service. An intriguing application is the use of a gold coating on an aluminium seal to ensure that, after a certain period of immersion in sea water, the controlled corrosion induced by the bimetallic couple will cause the seal to break. Gold is also used, because of its high reflectivity in the infra-red, to coat the reflectors used in drying equipment.

Over many years there has been a slow growth in what is facetiously termed 'dirty plating', the deliberate addition of solid particles to an agitated plating solution in order to incorporate them in the deposit. The first application to become established was the incorporation of diamond particles in nickel to produce far better cutting surfaces on burrs, bits, routers, saws, etc. Using smaller particles of diamond or other hard materials, smooth wear-resistant coatings can be obtained. Nickel/silicon carbide is used to coat the cylinder walls of aluminum i.c. engines. Cobalt/chromium carbide has a special ability to resist high temperature fretting in aero-engine compressors.

One way of producing chrome finishes with a satin appearance, whether purely for decoration or specifically for anti-glare or other properties, is by incorporating particles of insoluble materials such as barium sulphate or silica in the nickel undercoat; this is often a less expensive procedure than mopping the deposit with an abrasive composition.

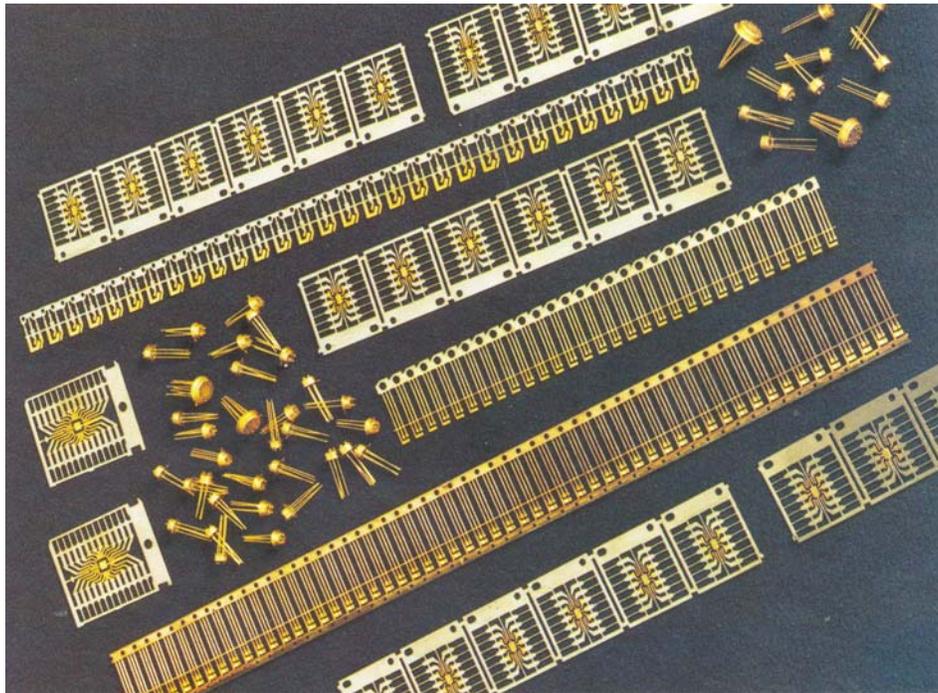
If very fine particles are used, the brightness of the coating is not affected, but discontinuities occur in a chromium top coat where the particles are present in the nickel surface; this is how microporous chromium coatings are produced.

All the electrodeposition processes referred to so far are carried out on work pieces that are fully immersed in the plating solution. Equipment is available, however, for local application of electrodeposited coatings by a method generically known as 'brush plating'. A tool of graphite is used, wrapped in absorbent cotton or polyester material soaked in plating solution. This is connected to the positive lead of a D.C. power supply, the article to be plated being connected to the negative lead. Plating begins as soon as the covered anode and work piece are brought into contact, and as it continues it is important that they are kept in motion relative to each other; in some cases the tool will simply be moved to and fro by hand, in others the work, or occasionally the tool, will be continuously rotated.

The conditions under which brush plating is performed are very different from those of ordinary plating, and so special solutions have been developed for the purpose. Most are proprietary and so their compositions are not disclosed; in general, they contain high concentrations of organically complexed metal ions. It is claimed that over 100 metals and alloys can be deposited by this method, considerably more than it is practical to apply by orthodox means. The coatings are not identical in properties with conventional deposits; chromium, for example, is significantly softer.

Brush plating is applied in many different industries, mainly but not solely for repair purposes. It is of outstanding value for applying coatings to areas of components that are too large to immerse in a plating bath or form part of structures that would be very expensive to dismantle completely (e.g. in ships, aircraft, etc). The technique could conceivably be applied under mass production conditions - at least one computer controlled brush-plating lathe has been made, which is capable of automatically depositing controlled thicknesses of coating on a succession of components.

Fig 14



Electrical applications

Coating properties important in electrical applications include resistivity, contact resistance, wear resistance, porosity and corrosion resistance, solderability, strength and ductility.

Contact resistance is especially important in electronics equipment where operating voltages may be very small. If a low contact resistance is to be maintained over a long life-time the contact material must be tarnish and wear resistant; if it is a coating, it must not only resist corrosion itself, but also be free from pores and penetrating cracks, so that there is no likelihood of substrate corrosion products ~spreading over the surface.

Electrodeposited golds, available in some variety, meet most requirements, with the much harder rhodium preferred on heavy duty rotary switches. (*Figures 14 and 15.*) Because of the high cost of these metals, however, there is constant pressure to economise by reducing the area coated and the thickness applied to the absolute minima, or by using alternatives.

BS 4292 specifies gold coatings between 0.5 and 20 μm thick for functional purposes, and for a long time the specification thickness for contact applications was 5 μm . This has now been lowered to 2.5 μm , subject to satisfying a porosity test. The fact is that by careful attention to substrate preparation, solution purity and process conditions, pore-free deposits can be produced at much lower thicknesses than used to be thought possible. Very thin coatings, sometimes diffused by heat treatment, are applied to components intended for use in controlled environments.

When gold plated articles are soft soldered, tin and gold are apt to form a brittle alloy, which may fail in use. The danger is avoided if the gold coating is not more than about 1 μm thick, as the alloy then formed has too low a gold content to be brittle. It is feasible to use such a coating on a nickel undercoat, but it is essential to ensure that the contact design minimizes wear. Nickel itself of course offers corrosion resistance, freedom from porosity, good mechanical properties and fair solderability; without a top coat of gold, however, it has too high a contact resistance for most applications.

At one time all-over plating with gold as an etch resist was common, but this is now a rare requirement. If gold is needed only on contact surfaces, various shielding techniques ('selective' and 'spot' plating) are used to limit the area plated to the minimum.

Palladium is the most promising alternative to gold and it has been widely used in telephone applications. There is reluctance to employ it on printed circuit boards, partly because of its reported tendency to catalyse the polymerization of organic vapours to produce partially insulating films; this danger has probably been exaggerated. A more conspicuous shortcoming is that, of existing palladium plating solutions, one group gives highly wear resistant but cracked, and therefore non-protective, deposits, while another produces deposits that are quite free from discontinuities but highly prone to galling. Fortunately, it appears that this difficulty can be overcome by applying the former coating on top of the latter. Bright palladium-

nickel alloy deposits, with quite high nickel contents, are also making headway in this area of application.

Laminates clad with high purity electrolytic copper are used in the manufacture of printed circuit boards. To make contacts through the thickness of a board, through-hole plating is practiced, employing electroless copper followed by a special copper electrodeposit. To facilitate soldering, which may be selective or carried out by a flow technique, a tin-lead alloy coating (40% lead) is usually plated on to the copper.

Specifications such as those of the European Space Agency require these coatings to be fused on to the copper, preferably by immersion in hot oil. This eliminates overhangs, prevents copper oxidation, improves solderability and assists inspection.

Fusing and soldering impose strains arising from the difference in coefficient of linear expansion between copper and epoxy/glass laminate. It is important that the copper should be able to accommodate these strains without cracking.

Because of its low resistivity copper is also used in much microwave equipment (wave guides, transponders etc.). At high frequencies all the current is carried in the outer layers of a conductor: the higher the frequency, the thinner the skin involved. In some cases, therefore, the still higher conductivity of silver makes it the preferred material, so a microwave conductor may be constructed of aluminium and electroplated with silver. On a component that is complex in shape, some recesses may have little or no coating, but this will generally be unimportant, as the total conductivity at high frequency will be hardly affected. If the part is to operate in a difficult environment, e.g. in a submarine, corrosion of the aluminium, accelerated by contact with the silver, may lead to early failure. In such circumstances, an undercoat of electroless nickel provides the answer. Where tarnish of the silver is unacceptable, a thin top coat of gold may be required.

The electrical resistance of electrodeposits may be markedly affected by the presence of alloying constituents. Electroplated silver has perhaps a 10% higher resistivity than metallurgically produced material. Alloying with antimony, bismuth or arsenic however, to increase hardness or brightness, may raise the resistivity by a factor of three or four.

Reliability is vital in electrical equipment required for defence, space and telecommunications purposes. In this area specialist advice should be sought during the design stage and appropriate specifications invoked to ensure the requisite quality is achieved and maintained.

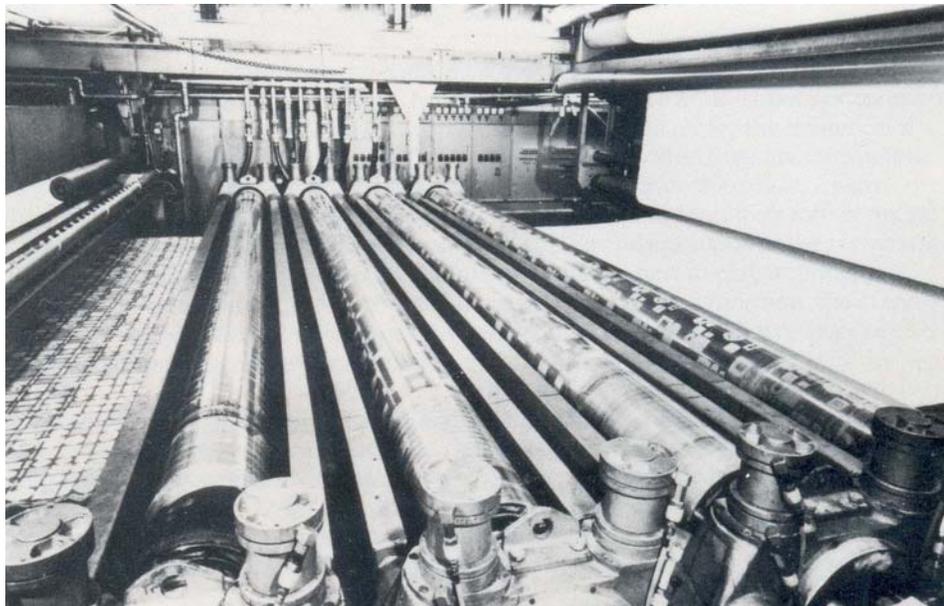
Electroforming

Coatings can be electrodeposited on some substrates and subsequently removed to form independent objects. The process is known as electroforming. The article on which the metal is deposited is usually termed a mandrel. Separation of the electroform from the mandrel is most often accomplished mechanically, the mandrel surface being chosen or treated so that too strong an adhesive bond is not developed. It is also feasible to employ mandrels that are dissolved, melted or collapsed to make separation possible.

The most important attribute of electroforming is its ability to replicate patterns and textures accurately in a rigid and durable material. Thus the oldest application is in the production of electrotypes for printing, and perhaps the most characteristic is in the production of gramophone record masters, mothers and stampers. Moulds and dies are made for moulding plastics, confectionery, glass and some metals, and for pressing sheet metal. Both copper and nickel are used in these applications, copper being favoured where high electrical or thermal conductivity are desirable and nickel where greater hardness, toughness and corrosion resistance are required. At present the largest use of nickel is in the manufacture of rotary screen-printing cylinders. (*Figure 16.*) Other mesh products include tobacco tapes, razor meshes and filters.

Continuous electroforming, especially of copper foil, on rotating cylindrical mandrels is practised on a large scale.

Figure 16



1. The nature of the electroplating process

Electrode reactions

Every electroplating bath contains electrically equivalent amounts of positively charged particles (cations) and negatively charged particles (anions) dissolved in a solvent, usually water. There are several different kinds of cation and anion in any single bath, together with unionized molecules of solvent and other possible substances, such as addition agents.

Electroplating is performed by passing a direct electric current through the solution between one or more anodes, connected to the positive terminal of the dc source, and one or more cathodes (the work to be plated), connected to the negative terminal.

In the external circuit, negatively charged electrons flow from anode to cathode via the power source. Within the solution, all the cations migrate under the influence of the electric field towards the cathodes and all the anions towards the anodes. Different types of ion move at different rates, depending mainly on their size and the magnitude of their charge. The sum of their movements in both directions produces a total flow of charge (i.e. current) equal to the external current.

Most anodes are soluble; that is, when the current is flowing the metal ions in their surface lose electrons and pass into the solution as ions. Once in solution the ions invariably become co-ordinated, either with water molecules to form aquo-ions (still generally known as simple ions, however) or with anions to form complex ions. Other reactions may occur at the anode, depending on the voltage difference between it and the solution, i.e. the anode potential. For example, water molecules or hydroxyl ions may be oxidized to gaseous oxygen. Where insoluble anodes are employed, as in chromium plating, this is the predominant anode reaction. Other substances present in the solution may also be oxidized at the anode.

The most important reaction at the cathode is the reduction of certain ions by electrons to give metal in the form of a coating. The ions reduced may be aquo-cations or complex anions. If the latter, they can move towards the cathode only under the influence of diffusion resulting from the concentration gradient developed as they are consumed, since the direction of the electric field is such as to tend to drive them away. Even when they are cations, their rate of discharge is always higher than their rate of arrival as part of the current flow, simply because some of the current is due to the movement of other ions. So in this case too diffusion has an essential part to play in bringing depositable ions to the cathode surface. The higher the rate of deposition, the steeper the concentration gradient with respect to depositing ions in the adjacent layer of solution and the lower their concentration at the cathode surface.

As the surface concentration of depositing ions gets lower, the voltage difference at the interface gets larger, i.e. the cathode potential becomes more negative, the effect being known as concentration polarization. The deposition process is subject also to activation polarization. This is the difference in potential required to drive the deposition reaction itself, even in the presence of an ample supply of depositing ions. Like concentration polarization, activation polarization increases with the deposition rate.

This interpretation is over-simplified, but perhaps complicated enough. It is worth taking a little trouble over it, as the consequences are so important.

Consider the question of competing cathodic processes: in the general case, metal deposition and hydrogen deposition. The considerations regarding polarization apply to both. If in particular circumstances, a single process accounts for virtually all the flow of current, raising the current density will increase the likelihood of the other process intervening. Indeed there is a maximum rate of deposition possible for any species, determined by its maximum rate of transport to the cathode. Beyond that, any increase in current must be accommodated by another reaction.

Common electroplating processes cover the whole gamut of possibilities. A rather noble metal like copper can be deposited at high rate from a simple salt solution (e.g. sulphate) with no simultaneous generation of hydrogen. The rather less noble nickel is also readily deposited from simple salt solution but some hydrogen is always liberated as well. The fact is that the activation polarization accompanying nickel deposition is high, while that accompanying hydrogen deposition, on a nickel surface, is low. Just as the hydrogen over-potential, as it is called, is low on nickel, so it is high on zinc. It is solely because of this that such a base metal as zinc can be deposited from acid solutions with high efficiency and even from complex cyanide solutions with moderately high efficiency. Although not quite as base as zinc, chromium does not fare nearly as well. It is usually plated from complex chromic acid solution and the competition with hydrogen evolution is so intense that at low current density only hydrogen is produced, and even at best, chromium deposition efficiency remains below 20%.

Co-deposition of hydrogen has many consequences. Low efficiencies are uneconomic in power terms. Bubble formation may cause pitting. Spray may be a serious problem. Discharge of hydrogen, by lowering the acidity of the solution next to the cathode, may cause basic compounds to be precipitated and incorporated in the deposit, to the detriment of its properties.

Important consequences follow from the trend in metal deposition efficiency with increasing current density. If this is downwards, as is often the case when metal is deposited from complex ions, coating thickness distribution on a shaped article will be improved. On the other hand, if the efficiency increases with current density, the non-uniformity of coating thickness is aggravated. This question is considered more fully below.

Current and coating thickness distribution

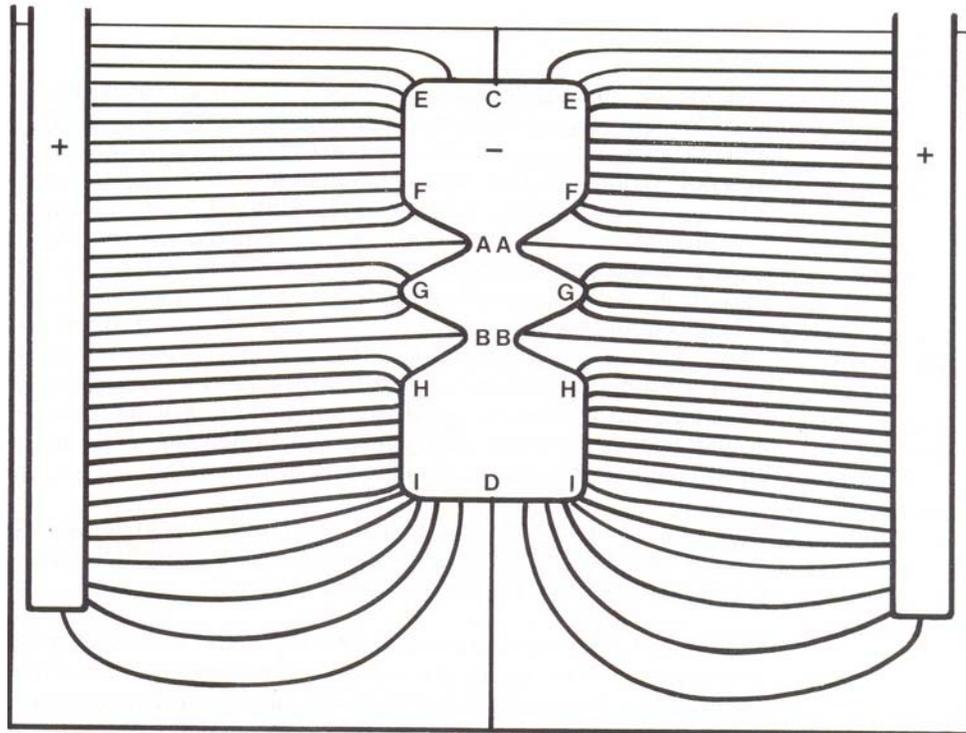
The voltage difference between the positive and negative electrodes of a plating tank is made up of the anode and cathode potentials, which have already been considered, and the voltage drop across the solution itself, which has a resistivity roughly of the order of $10 \mu\Omega$. The current automatically distributes itself in such a way as to minimize the total voltage difference. The pattern is best understood by considering first the limiting case in which both electrodes are regarded as being uniformly polarized (or unpolarized). This pattern is the 'primary current distribution'. It is a function of shape only, independent of size and of the magnitude of the electrical parameters, voltage, current and resistance. The pattern is common in physics, identical to that adopted in ideal circumstances by the lines of flow in thermal and mass-transport fields and indeed by the lines of force in electrostatic and magnetic fields. Theoretically, it can be deduced from the geometry alone. In practice, it is possible to determine it accurately only for simple configurations, although estimates can be obtained by the known methods of numerical analysis using a computer.

Figure 17 is a free-hand diagram of the current-flow field between flat anodes and a shaped cathode. The electrodes are assumed to be long in the direction perpendicular to the paper, the field thus being two-dimensional.

The current density on the surface of the electrodes is inversely proportional to the distance apart of the points at which adjacent current lines meet the surface. It can be assumed that the current density does not vary a great deal over the faces of the anodes, as these are flat and some distance from the cathode, and so for simplicity it is represented as uniform. Over the cathode, however, the current density varies by about an order of magnitude.

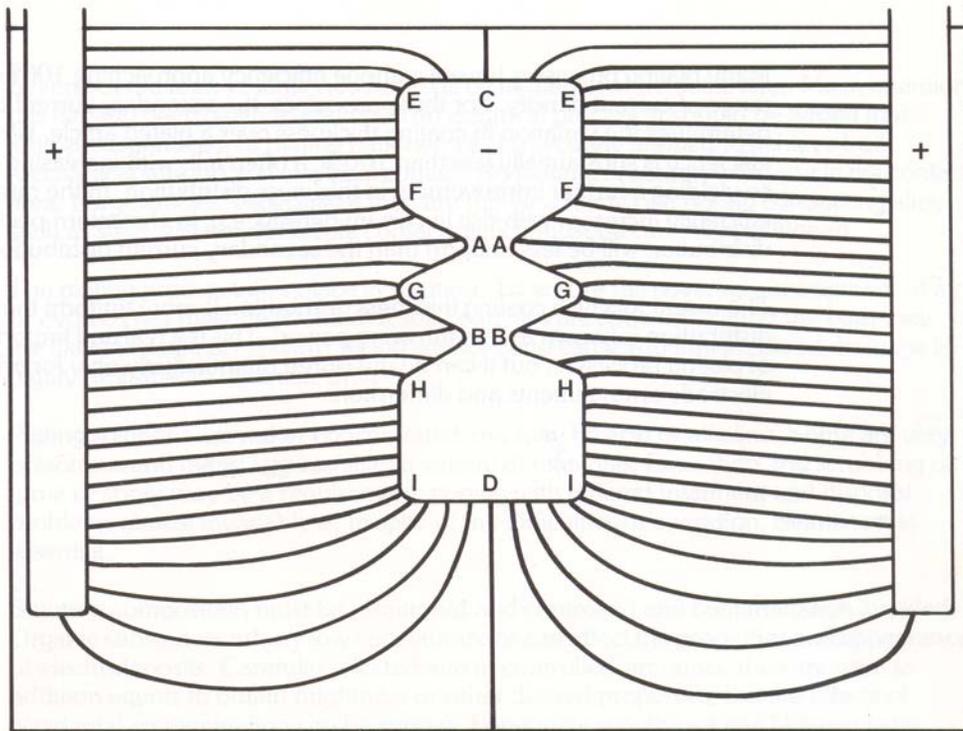
It is lowest at the bottom of the recesses, at A and B, because of restricted access, due to the limited width of the current paths supplying the recesses and competition from the neighbouring prominences. Distance from the anode is another factor, but not the most important. Notice for instance that C and D are further from the anodes than A and B, yet the current density at both points is higher. It is lower at C than at D, because of the narrowness of the current path between the top of the cathode and the surface of the solution compared with that between the bottom of the cathode and the base of the tank. This difference illustrates another feature of current flow patterns, that they spread to occupy the whole cross-section of conductor (in this case, solution) available to them.

Figure 17 Primary current distribution over shaped cathode.



The current density is high on all the prominences, E, F, G, H and I. It is highest at G because of the high convex curvature here and the deep recesses on either side. It is almost as high as I, because the radius of curvature is fairly small, the bottom of the cathode does not compete strongly, and there is the boost in this region resulting from the projection of the anodes beyond the cathode and the wide current path below the electrodes. Similar influences operate at E, rather less strongly; giving a current density slightly higher than at H, where again it will be a little higher than at F, because of the transmitted effect of the more favourable current flow below, than above, the cathode.

Figure 18 Secondary current distribution over shaped cathode.



The drawing in (*Figure 17*) is too crude to show all these minor differences, but the principles underlying them are important.

The reality, however, always differs from this representation. Because of concentration and activation polarization, the potential difference between the cathode and the adjacent solution is always higher where the current density is higher. The cathode, being a metallic conductor, maintains an approximately uniform potential, so it is the potential of the solution adjacent to its surface which varies, being less negative where the local current density is high than where it is low. The potential difference in the solution phase between cathode and anode is therefore significantly less for points E, F, G, H and I in *Figure 17* than for points A, B, C and D. Hence the extent to which the flow of current favours the former set of points is moderated, and the current density variation is diminished. The 'secondary current distribution', as it is called, is thus less extreme than the primary current distribution. The extent of the difference depends on the particular plating process. It can be large, lowering the ratio of maximum to minimum current density by a factor of perhaps four or five, but complete uniformity is out of the question, as differences in current density are necessary to maintain the potential variations that produce departure from primary current distribution.

(*Figure 18.*)

Many plating processes have a cathode efficiency approaching 100% over a wide range of current density. For these processes, the secondary current distribution determines the variation in coating thickness over a plated article. Where cathode efficiency is substantially less than 100%, it often falls with increasing current density, so yielding a further improvement in thickness distribution. In the rare cases in which efficiency increases with rise in current density, e.g. in chromium plating, the thickness distribution will be less uniform than the secondary current distribution.

The extent to which coating thickness distribution is more uniform than primary current distribution is known as the 'throwing power'. This is a real and important characteristic of plating processes, but it can be measured quantitatively only for arbitrarily defined electrode arrangements and dimensions.

General considerations

Several of the topics mentioned here will be treated in more detail later. Much attention has already been given to plating as an electrical process. It should be added that articles suspended in a plating bath need to be securely gripped to achieve both mechanical support and electrical contact. No plating, of course, will occur in the contact area. Large articles, especially if they are thin and made of a poorly conducting alloy such as steel, will need multiple contacts which must be carefully positioned.

The plating process takes place in solution. To ensure full coverage, entrapment of air or evolved gas must be avoided. If solid particles are allowed to enter the bath they are likely to settle on upward-facing surfaces and cause roughness. Good drainage is highly desirable to minimize drag-out.

Plating solutions are rather concentrated and may be acid or alkaline. Some are very poisonous and many aggressive to a variety of materials. Extraction and scrubbing of fume or spray may be a requirement; coping with effluent treatment and disposal problems almost invariably is. In spite of the difficulties of operation, cleanliness is essential.

Solution composition must be monitored and controlled and contamination avoided.

Organic substances in very low concentrations can affect the properties and appearance of electrodeposits. Carefully selected and in controlled amounts, they are used as addition agents to obtain brightness or other desired properties, but the effects of accidental contamination can be serious. Foreign inorganic ions can likewise have deleterious effects.

Methods exist for removing many impurities from plating solutions, but it is especially important that they are not continuously introduced into the solution, for example, via the work itself. In some cases it is virtually impossible to prevent this occurring. In the plating of tubular steel furniture some iron is almost certain to dissolve from the inside of the tubes, and it is therefore desirable to choose processes able to tolerate this.

Good quality, adherent coatings can be obtained only if the basis metal is chemically clean: free from grease, oxide films, etc. Preparative treatments generally comprise several stages, with intermediate rinses, and may differ substantially according to the nature of the substrate. Suitability for plating is something that ought to be considered at an early stage in design. Apart from the particular problems that individual materials present, it should be noted that assemblages of different materials may pose exceptional difficulties. Means may be found to overcome these, but generally speaking, where possible, it is preferable to plate components separately and assemble them afterwards.

Cost factors

The design of an article rarely makes the plating of it impossible, but it may make it unnecessarily difficult; generally speaking, the more difficult, the more expensive. If cost effectiveness is the target, if one wants to obtain the desired properties and appearance for the lowest overall cost, it is helpful to have some understanding of the problems that the metal finisher has to deal with.

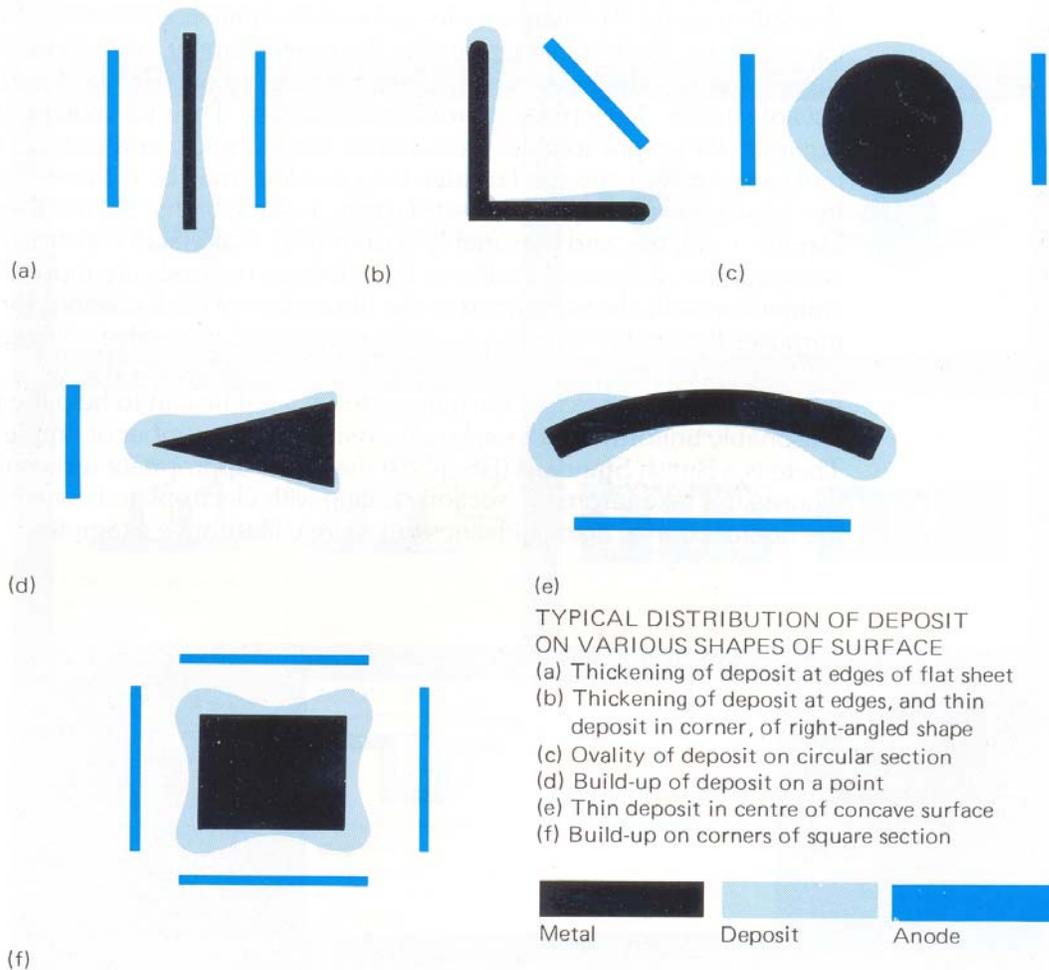
Overall cost is emphasised, however. Finishing is only one part of the manufacturing process and should not be considered in isolation. Increased finishing costs may be justified if they allow greater savings to be made elsewhere. On the other hand, it may be worth spending more in other directions to economize in finishing; to take a particular example, buying pre-finished instead of cold-rolled steel to make the pressed sides of electric toasters may reduce the overall cost of manufacture by enabling mechanical polishing to be omitted or much reduced.

Good and bad design

Coating thickness distribution

It was explained in section 2 why it is that electrodeposits tend to vary in thickness over the surface of a single article. Deep recesses present the biggest problem, but the distribution obtained over apparently simple shapes may be surprisingly uneven unless special precautions are taken. All edges and corners attract more than their fair share of current. As a rough guide, the average coating thickness on a flat rectangular sheet, nickel plated in a bath of much larger length and depth, may be twice the thickness achieved at the centre of each face. Figure 19, taken from a booklet on Design for Electroplating by D.N. Layton, published by The International Nickel Company (Mond) Limited (now Inco Europe Limited), gives an idea of how coating thickness varies over certain typical shapes.

Figure 19



The plater has at his disposal various ways of improving distribution. They could be classified as ordinary and extraordinary means.

It might be thought that the most ordinary of ordinary means would be to choose a plating solution with good throwing power, but this is an option that is only occasionally available. It can be done if characteristically different processes exist for depositing the same metal; it is not much use, however, offering a cyanide copper deposit where a hard chromium coating is required.

The principal ordinary means are: choice of appropriate anode size and position, with use of conforming anodes where possible; and judicious arrangement of components in relation to each other to achieve a degree of mutual shielding or compensation. These procedures can be quite effective.

The extraordinary means are the use of shields, burners and auxiliary anodes. Shields are non-conductors, such as sheets of plastic, shaped and positioned so as to obstruct the flow of current to prominences. Burners, sometimes known as thieves or robbers, are auxiliary cathodes, often simple wire frames, placed where they can draw excess current away from edges and corners; they are, of course, inherently wasteful of the depositing metal. Auxiliary anodes are not as widely used as might be expected.

Connected to the positive terminal of the power supply, or sometimes an auxiliary supply, they can be located near or within recesses or holes so ensuring an adequate flow of current. They present problems, however. Their positioning must be very accurate. If they are soluble, they change shape rapidly and so need frequent replacement, and any solid residue they produce may be a cause of roughness.

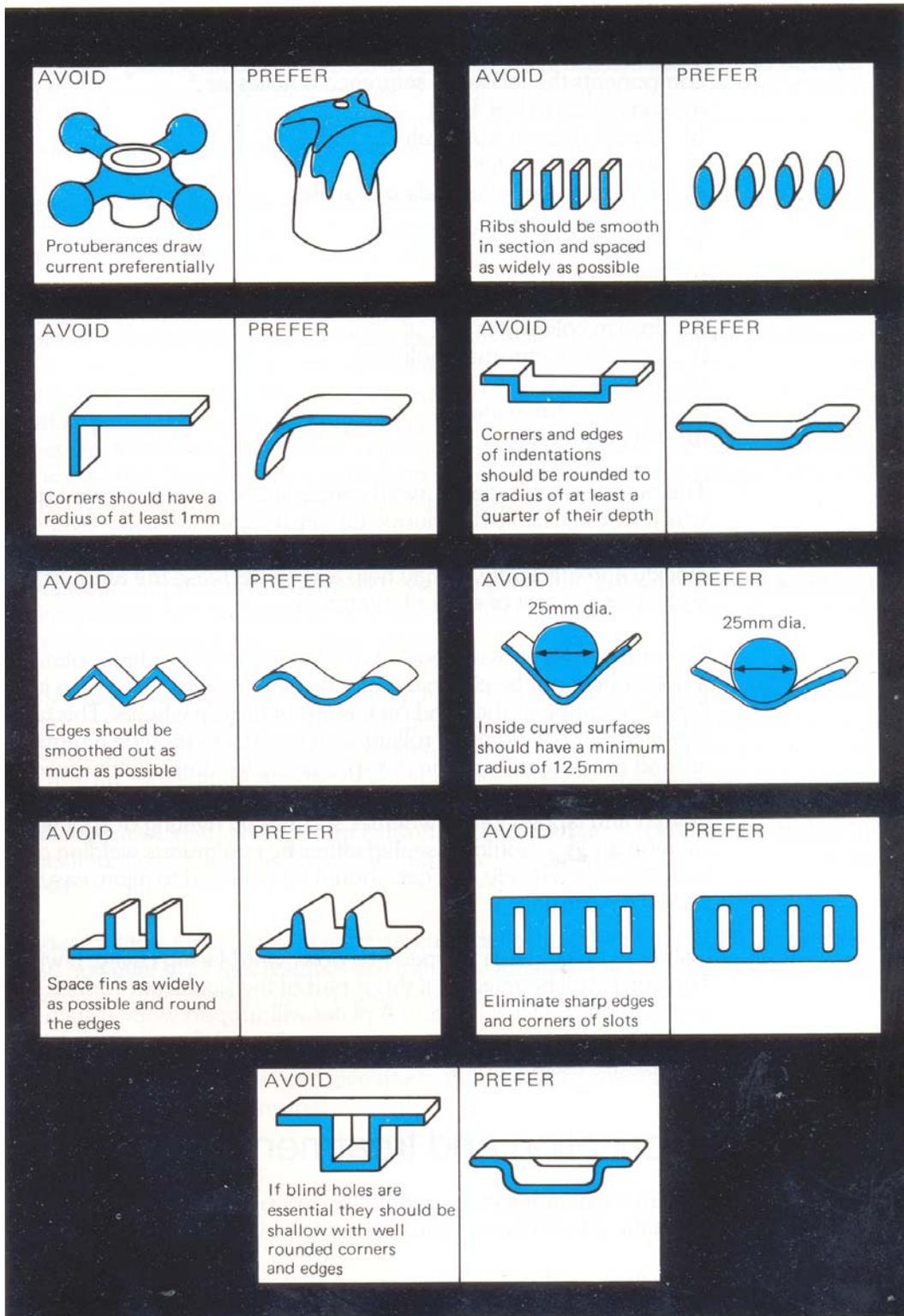
Insoluble anodes are perfectly satisfactory in some baths, but in others it is hard to identify a suitable, and reasonably economical, material of construction. The consequence of these difficulties is that all these methods are more likely to be used in connection with electroforming or the deposition of thick coatings for engineering purposes than in the application of decorative and protective coatings.

It is in the manufacturer's own interest to do what he can to help the plater achieve a reasonably uniform thickness, by observing a small number of simple design principles.

There is a British Standard (BS 4479) that gives appropriate recommendations.

Figure 20 is taken from the section dealing with electroplated coatings. The diagrams are not, of course, rigid guidelines but merely illustrative examples.

Figure 20



Rinsing and drainage

It is easy to appreciate the importance of good drainage if one considers the many stages involved in a typical plating operation. To zinc plate and passivate mild steel components the following sequence is necessary:

- a) soak clean in hot alkali
- b) anodic clean in hot alkali
- c) rinse in cold water
- d) acid dip to remove oxide and scale
- e) rinse in cold water
- f) rinse in cold water
- g) zinc plate
- h) static rinse to conserve plating salts
- i) rinse in cold water
- j) immerse in chromate solution
- k) rinse in cold water
- l) rinse in warm water
- m) dry in warm air

The rinses are essential to avoid contamination of subsequent processing solutions, which would usually deteriorate rapidly if significant carry-over occurred. The design of the component plays an essential role in enabling this vital rinsing to be accomplished quickly and efficiently. It may help also to decrease the amount of water consumed and lower the cost of effluent treatment.

The first need is to avoid pockets and blind holes in which solution can be retained. If hollows cannot be eliminated entirely it may be necessary to insert drainage holes. A good example is the bead on the rim of bicycle wheels. This cannot easily be sealed completely, by welding or rolling, so it is usual to provide a number of small holes around the periphery of the rim specifically for drainage purposes.

Folded and lapped joints, whether secured by riveting or spot welding, tend to retain solution and so should be sealed either by continuous welding or by filling with inert material; alternatively, the gap should be enlarged to allow easy drainage and satisfactory rinsing.

If air or evolved gas is trapped in a downward facing cavity, it will prevent plating. The article will be rejected if this is part of the significant surface, and may suffer rapid corrosion in service if it is not. A plater will support work in such a way as to avoid this problem, but his room for manoeuvre is limited. In some cases it will be necessary to provide gas escape holes.

Fabrication and treatment processes

The choice of fabrication method for any article is subject to many constraints, and one is the effect it has on subsequent finishing processes.

The influence of shaping operations on the quality of surface is important. Where deep drawing of sheet is employed, it is worth ensuring that the press tools have a

good finish. A lubricating and protective film should also be used to avoid scratches and other surface defects, so minimizing the cost of polishing operations.

The cost of plating die castings, both in terms of the processes that have to be used and the percentage of rejects incurred, is highly sensitive to surface quality. Care taken in designing the die to obtain smooth metal flow, in finishing the mould surfaces, and in establishing optimum process conditions is well repaid.

The effect of design shape on coating thickness uniformity and the trapping of gas or fluid is independent of the way the component is produced, but there are additional considerations if the process involves solidification, e.g. casting of metals or moulding of plastics. A plated finish draws attention to any imperfections. Thus, it is best to avoid large, flat areas, and to prefer either convex or textured surfaces. Where ribs are required, they should be thinner than the main wall, to avoid visible sink marks on the outer surfaces. They should be tapered and radiused, both where they meet the wall and at their outer edge. Bosses also should be tapered and radiused, and made as short as possible; they should preferably be cored to give minimum wall thickness.

If they are to take inserts of other materials, it is better for them to be put in after plating. If it is essential, however, to mould them into the component, the compatibility of the material used with all the processing solutions should be verified.

In plating plastics, it should be remembered that many polymers lose strength at the processing temperatures. Wall thicknesses must be sufficient to prevent distortion and racking points (where significant pressure may be applied), strong enough to withstand distortion or situated in non-critical areas.

Joined plastics, whether welded or cemented, can rarely be successfully plated. Welded metals do not present such great difficulty, although, as already mentioned, welds can create trouble if they trap processing solutions. A heavy scale may be associated with gas and arc welding. Removing it, whether mechanically or chemically, is an extra process stage and may give rise to roughness requiring further treatment. If greasy surfaces are welded, an adherent carbonaceous film may be produced, which is more difficult to remove than ordinary welding scale; it is preferable in such cases to degrease before welding.

Soldered joints rarely present any particular difficulty. The plater will have to make sure, however, that flux residues are removed and that the processing solutions have no adverse reaction with the components of the solder.

. Any post-fabrication operations should be scrutinized for possible effects. Heat treatment, for example, could give rise to heavy scaling; it is important to select treatments and conditions that avoid this.



Types of plant

Rack plating

Where possible, small parts are plated in bulk, i.e. in barrels as described in the next section. Many small parts, however, and nearly all large parts are plated on racks.

A rack, or jig, is an electrically conducting frame, of copper, brass or aluminium, with a hook at the top to engage the cathode bar and spring contacts, of phosphor bronze, stainless steel or titanium, to support the components and conduct the current to them.

The whole surface, except for the contact areas, is coated with chemically resistant and insulating plastic. Small parts, in particular, are sometimes secured by copper wire, twisted round them and stretched between simple lugs at the top and bottom of the frame.

The loaded rack is immersed for the plating operation in a vat, or tank, of plating solution, already containing anodes supported in appropriate positions. The tank will be fitted with a pump and filter, providing continuous circulation of the solution and ensuring the removal of any solid impurities. There will be some means of heating (and sometimes cooling) and some form of agitation, either by injection of compressed air (free from oil and other impurities) or by movement of the cathode relative to the solution.

The tanks used vary widely in size, and may be manually or automatically operated.
(*Figure 21.*)

Components plated on racks may be held the same way up throughout the process, and should be free from hollows liable to retain solution or air. They must have areas where contact marks can be tolerated. With these minor limitations, articles of almost any shape or size can be rack plated, provided suitable plant is available.

Barrel plating

The characteristic feature of barrel plating is that no permanent contact is established with any individual article. The items being plated comprise a sliding and tumbling bed within a rotating vessel, i.e. barrel, of insulating material. Fully immersed barrels are the most common. These are usually prismatic (often hexagonal) or cylindrical in shape, with perforated walls, and rotate about their horizontal axis. The anodes are outside the barrel, and cathode contact is made by various means, most often via the ends of insulated cable dipping into the bed (danglers). Many automatic plants are in operation employing this type of barrel. (*Figure 22.*) Open ended barrels are much less used than formerly, but can be very economical and are suitable for very small items. These have no perforations, and the plating solution is retained inside them.

They are usually narrower at the mouth than at the base, may have flat or curved walls, and rotate during plating with their axis inclined at about 45° to the vertical. The anode is a disc of metal supported from above, while the cathode contacts are mushroom headed bolts penetrating the base.

The main advantage of barrel plating is that it eliminates the need for racking, with its expensive labour content. It also avoids contact marks, and carries very little risk of roughness, pitting or high current density burning. Coating thickness distribution is more predictable and often better than is obtained with rack plating, because the current is better distributed and partly because the tumbling action may abrade the softer coatings on projecting areas.

Figure 22

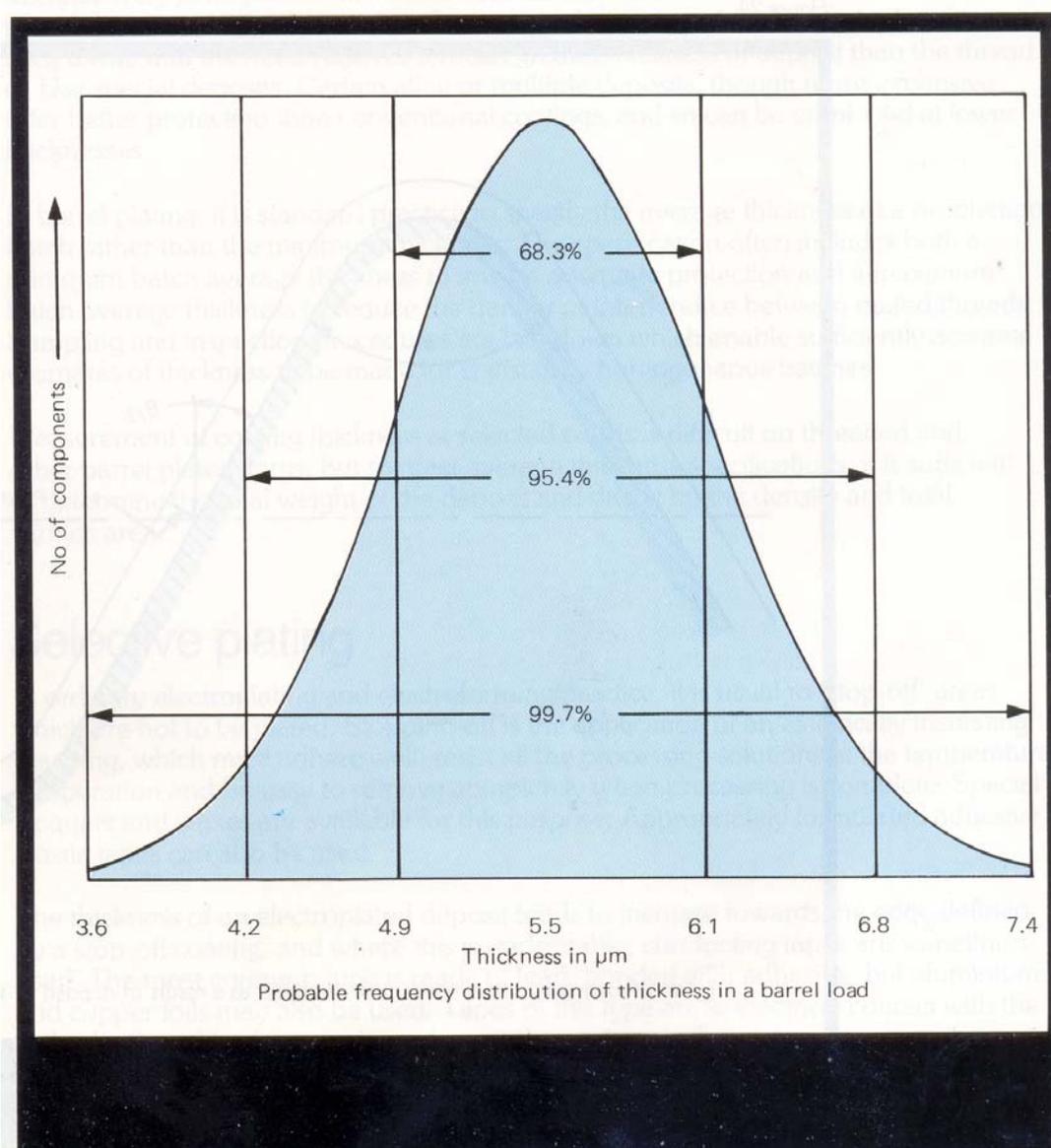


Barrel plating cannot be applied, however, to large or easily damaged components, or to any requiring a mirror smooth surface. Parts that tend to become entangled with each other or stick together can sometimes be plated in small loads in special barrels.

Shielding or stopping off is not feasible in barrel plating. Thickness variation from one article to another in the same load is governed by a typical bell-shaped frequency distribution curve; it may be necessary to establish a high average in order to ensure a given minimum thickness. (Figure 23.)

Most electroplated finishes can be applied by barrel methods, but a special type of equipment is required for chromium plating, which imposes tighter limits on the sort of components that can be processed.

Figure 23



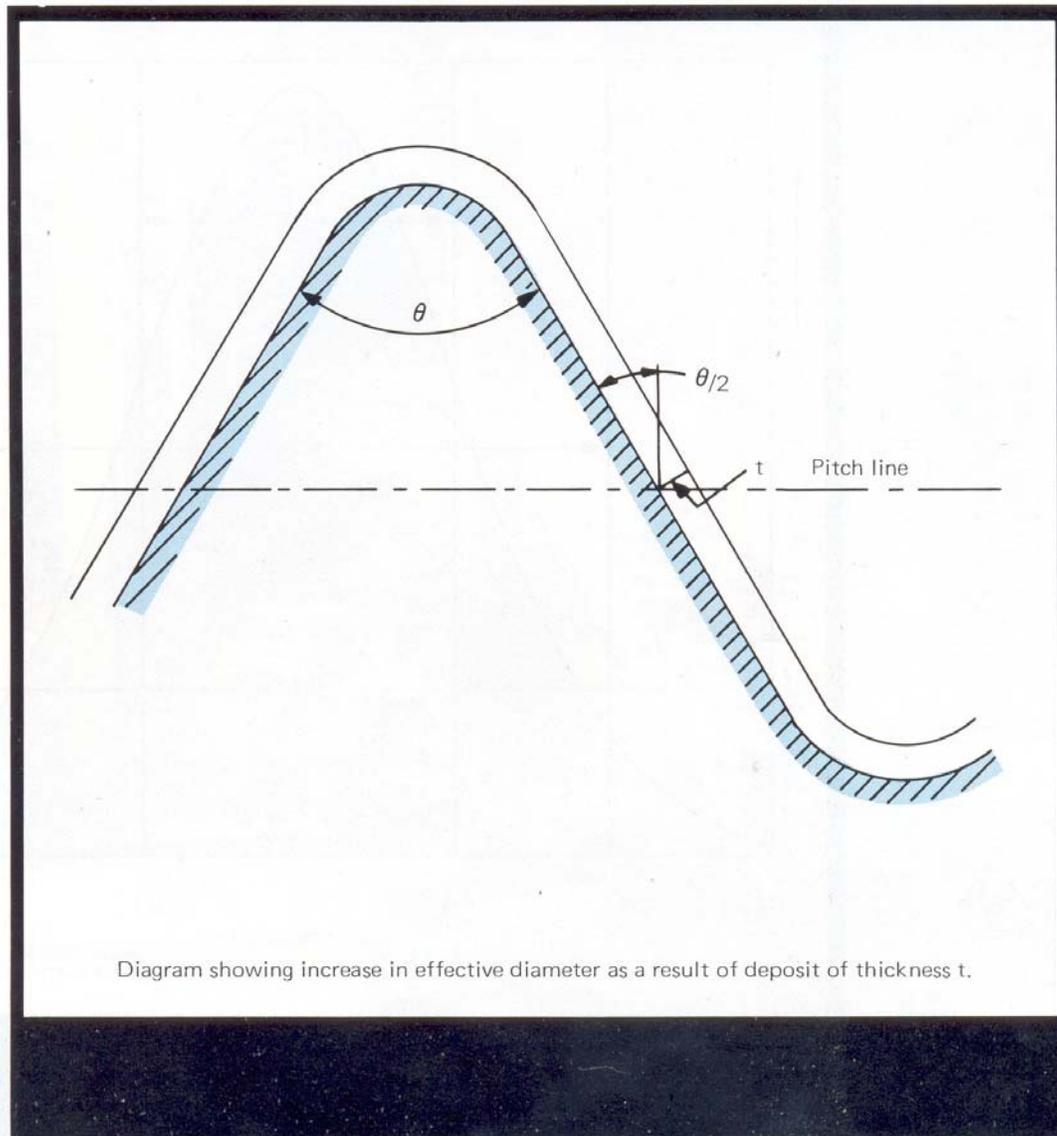
Many types of article are successfully barrel plated, most of them small, but including certain things, such as spanners, up to quite large sizes. Among the components processed in the largest quantities are threaded fasteners, bolts, screws, nuts etc.

Thicknesses of coatings adequate for most purposes are specified in BS 3382: Parts 1-6.

Thicker coatings may be required in some applications, but a risk arises that they will interfere with the free engagement of the male and female threads. Even a uniform coating of thickness, t , applied to an external screw thread, increases its effective diameter by about $4t$, given a typical angle between the flanks of the thread.

(Figure 24.) The effect is accentuated by the tendency for thickness to increase towards the crest of the thread and the end of the component, and by the variability between one fastener and another. On internal threads, the deposit is concentrated on the first one or two threads at each end.

Figure 24



These problems are well understood, and a further section of the British Standard mentioned above (BS 3382: Part 7) describes the following practices that may be adopted to accommodate them.

- a) Accept some risk of interference, necessitating a degree of selective assembly. The risk can be estimated from the scatter of plating thickness and dimension tolerances, and is usually quite small, so that this practice is often acceptable, except where automatic assembly methods are used.
- b) Make a special allowance on thread dimensions. External threads may be produced undersize or internal threads oversize to leave room for the specified coating.
- c) Adjust the thread dimensions by chemical or electrochemical treatment before plating. This is appropriate where quantities are too small to justify special manufacture of threads with sufficient allowance.
- d) Selectively plate parts of fasteners. This cannot be done if the fasteners are barrel plated, but it is standard procedure for bumper bar bolts, which are rack plated in such a way that the head receives a much greater thickness of deposit than the thread.
- e) Use special deposits. Certain alloy or multiple deposits, though more expensive, offer better protection than conventional coatings, and so can be employed at lower thicknesses.

In barrel plating, it is standard practice to specify the average thickness of a production batch rather than the minimum thickness. The specification often includes both a minimum batch average thickness to ensure adequate protection and a maximum batch average thickness to reduce the danger of interference between mated threads.

Sampling and inspection procedures are laid down which enable sufficiently accurate estimates of thickness to be made for statistically homogeneous batches.

Measurement of coating thickness at selected points is difficult on threaded and other barrel plated items, but to meet average thickness specifications, it is sufficient to determine the total weight of the deposit and divide by the density and total surface area.

Selective plating

In ordinary electroplating and electroforming practice, it is usual to 'stop-off' areas which are not to be plated. Stopping-off is the application of an electrically insulating covering, which must adhere well, resist all the processing solutions at the temperature of operation and be easy to remove completely when processing is complete. Special lacquers and waxes are available for this purpose. Appropriately formulated adhesive plastic tapes can also be used.

The thickness of an electroplated deposit tends to increase towards the edge defined by a stop-off coating, and where this is undesirable, conducting tapes are sometimes used. The most common type is made of lead, bonded with adhesive, but aluminium and copper foils may also be used. Tapes of this type are in electrical contact with the cathode; they therefore receive a deposit themselves and so act as thieves.

Occasionally, when the work comprises a succession of identical, accurately machined parts, it is worthwhile machining a metal mask to cover the area that is to receive no plate; this also acts as a thief, but can be stripped and re-used.

A method of selective plating that is being increasingly applied in the area, especially, of gold plating for contact applications is based on the flow cell principle. The limited areas that are to be plated are left exposed when masks, often of silicone rubber, are pressed against them. Plating solution is circulated rapidly through the cell and a current is passed. Under these hydrodynamic conditions, current density can be high and plating times correspondingly short.

Brush plating, already described in section 1.3.3, offers another means of controlling the distribution of an electroplated coating. It is difficult with this method, however, to define accurately the boundary between plated and unplated areas, and so if this aspect is important it is necessary to employ normal stop-off methods to shield the areas that are not to be coated.

Continuous plating

Steel and other metals or alloys, in the form of sheet or strip, are continuously electroplated in highly specialized plant, often at very high rates. A coating of uniform thickness may be applied to both sides or to one side only of the strip. Articles can be made from the pre-coated metal by normal fabrication procedures and frequently require no further electroplating operations. The best known example is the production of tinplate and its use mainly in the manufacture of containers. Continuous electroplating with other metals, such as zinc and nickel, is also well established.

The continuous plating of wire is another important industrial process. Particular applications are tin coated copper wire for electrical use, zinc plated steel wire for ropes and hawsers, and brass coated steel wire for use in tyres.

For the economical manufacture of components required by the electronics industry, reel-to-reel plating is coming into increasing use, the principal coatings applied being gold and tin-lead. A simple coated strip may be produced, then blanked and formed to yield the finished components. Often, however, the basis material is pre-blanked but held together at one or both edges, so that it can still be plated continuously, and possibly undergo other manufacturing stages, before being separated into individual components. Selective plating using permanent masks, as described above, is increasingly common in reel-to-reel as well as batch plating

Plating processes

This section is intended for reference only. It provides basic information about the principal processes available for deposition of the more important plated metals and alloys. It does not pretend to be comprehensive, but there are many texts available to which reference could be made for a fuller and more detailed view. Metals are listed in alphabetical order, and the information concerning each process is tabulated in standard form to aid consultation.

Table 4. Characteristics of selected plating processes.

Coating metal bath type	Principal constituents	Acidity or alkalinity	Temperature	Plating rate	Throwing power	Major uses
Cadmium cyanide	sodium cyanide cadmium oxide (brighteners)*	alkaline	cool	medium	good	functional
Chromium hexavalent	chromic acid sulphuric acid (potassium silicofluoride)	acid	warm	low	poor	decorative functional
trivalent	chromium salt conductivity salt complexant	slightly acid	cool to warm	low	good	decorative
Copper acid	copper sulphate sulphuric acid (brighteners and levellers)	acid	cool	medium	poor/fair	functional , levelling undercoats
cyanide	sodium cyanide copper cyanide (other salts hydroxides)	alkaline	hot	medium	good	general undercoats
pyrophosphate	potassium pyrophosphate copper pyrophosphate (salts brighteners and levellers)	slightly alkaline	warm	medium	fair	functional undercoats
electroless	sodium potassium tartrate copper sulphate (salts, hydroxides) plus formaldehyde	alkaline	cool to warm	low	excellent	functional

Coating metal bath type	Principal constituents	Acidity or alkalinity	Temperature	Plating rate	Throwing power	Major uses
Copper-zinc (brass) cyanide	sodium cyanide copper cyanide zinc cyanide (brighteners)	alkaline	cool	low	good	decorative adhesion to rubber
Gold cyanide	potassium gold cyanide potassium phosphate (brighteners alloying additions)	slightly alkaline	hot	low	good	decorative
acid	potassium gold cyanide potassium citrate citric acid (phosphates alloying additions)	slightly acid	warm	low	good	electrical decorative
Lead fluoborate	lead fluoborate fluoboric acid grain-refining additions	acid	warm	high	good	protective (sulphuric acid)
Lead-tin fluoborate	lead fluoborate tin fluoborate fluoboric acid grain-refining additions	acid	cool	medium	good	high lead bearings high tin solder
Nickel Watts	nickel sulphate nickel chloride boric acid (brighteners levellers, anti- pit agents)	slightly acid	warm	medium	fair	decorative functional
Sulphamate	nickel sulphamate boric acid nickel chloride (anti-pit agents)	slightly acid	warm / hot	high	fair	functional
electroless	nickel sulphate (or chloride) sodium salt of a carboxylic acid plus sodium hypophosphite*	slightly acid	hot	low	excellent	functional

*Borohydrides or alkylamine.boranes give Ni-B instead of Ni-P deposits

Coating metal bath type	Principal constituents	Acidity or alkalinity	Temperature	Plating rate	Throwing power	Major uses
Silver cyanide	potassium cyanide silver cyanide potassium carbonate (brighteners or hardeners)	alkaline	cool	medium	good	decorative functional
Tin stannate	sodium stannate sodium hydroxide (or potassium salts for higher plating rate)	alkaline	hot	medium	good	protective electrical
Acid	Phenol sulphonic acid (and/or sulphuric acid) stannous sulphate grain-defining additions (or brighteners)	acid	cool	high/ medium	fair	continuous or barrel: functional bright; decorative
fluoborate	fluoboric acid tin fluoborate boric acid	acid	cool/warm	high	good	wire bearings
Zinc cyanide	sodium cyanide sodium hydroxide zinc oxide (brighteners)	alkaline	cool/warm	medium	good	protective decorative
zincate	sodium hydroxide zinc oxide (brighteners)	alkaline	cool	low	good	general (but cyanide free)
acid	zinc sulphate (or zinc chloride) other salts (brighteners)	slightly acid	cool/warm	medium	fair	wire cast and wrought iron

Preparation for plating

General

The nature of the basis material and the fabrication processes it has undergone have a major influence on the treatments required prior to plating. The particular coatings to be applied and the intended use of the finished article may also affect the choice made.

The quality and adhesion of electroplated coatings are critically dependent on the surface condition of the substrate. Films and any other contaminants must be removed.

Slight attack, at least, on the surface itself is generally desirable, to eliminate any disturbed outer layer and expose a clean, firm structure, but there is no need for the surface to be roughened. The usual sequence is to clean, then to etch lightly, although some materials may suffer slight attack during cleaning. With heavily scaled components it may sometimes be necessary to clean, pickle, then clean again. Special treatments or undercoats required for particular materials will be considered in the later sections, but it is convenient first to review the general range of pretreatment processes.

Cleaning processes fall into two broad classes, solvent-based and alkaline. Alkaline cleaning is virtually essential, but it may often be advantageous to solvent-clean first.

Organic solvents, such as trichloroethylene and perchloroethylene, are often used hot in vapour or liquid-vapour degreasers. Inhibitors are added to the solvents to prevent their decomposition, but there are some solvent-metal combinations that must be avoided. When contaminated, the solvents are purified by redistillation in the degreasing plant itself.

Emulsifiable solvents are used as soak cleaners. They contain surface active agents, which cause them to be emulsified in a subsequent water rinse and so removed along with the soil.

In what is known as emulsion cleaning, the solvent is pre-emulsified in water, again using suitable wetting agents. The procedure is most effective if the emulsion is used hot.

Alkaline cleaners may contain sodium hydroxide and alkaline salts such as metasilicate, carbonate, cyanide, tripolyphosphate or hexametaphosphate, as well as wetting and sequestering agents. The sodium hydroxide may be omitted, however, where only a light-duty cleaner is required, and cyanide is not necessary if a powerful wetting agent is selected. The cleaners are used hot, the work usually being immersed for a few minutes, although spray cleaning also is effective.

The cleaning process can be speeded up by simultaneously passing an electric current. The gas generated on the surface of the work contributes a valuable scouring action. As there is more hydrogen liberated at a cathode than oxygen at an anode for a given flow of current, cathodic cleaning is often preferred. It cannot be used, however, where there is any danger of hydrogen embrittlement; and, because of the likelihood of

substances being cathodically deposited on the surface, it is often followed by a brief anodic treatment (occasionally, the current is reversed several times). Cathodic cleaning is used alone, however, on metals that are rapidly etched under anodic conditions.

Cleaning is usually followed by a rinse in water, then a dip in a dilute mineral acid solution, followed by a further rinse, before entering the plating bath. The function of the acid dip is to neutralize the alkali remaining on the part, dissolve any oxide film that might have formed and etch the surface slightly.

Sometimes the acid dip is replaced by an electrolytic acid etch.

Iron and steel

It is usual with low-carbon steel to clean first in a solvent or strongly alkaline soak cleaner, pickle if necessary in strong acid, and then clean again in a separate alkaline cleaner, usually under anodic conditions. After rinsing, the parts are given a brief dip in dilute hydrochloric acid solution, and then rinsed twice before being placed in the plating tank.

Where the strongest adhesion is required, an anodic etch in sulphuric acid solution may replace the acid dip. A similar procedure is used for cast iron, but it is important in this case to etch at high current density for only a short time; it may then be necessary to brush away any loose carbon and re-immerses briefly in the etch solution without current.

High-carbon steels are prone to hydrogen embrittlement and cleaning steps involving the generation of hydrogen should be avoided or strictly limited. Hardened steels should, if possible, be stress relieved by heat treatment before plating. Preparation for plating is otherwise similar to that recommended for low-carbon steels, except that an electrolytic etch is essential; it is sometimes preceded by an acid dip and anodic electroclean (to remove smuts), with intermediate rinses. These steels should be heat treated as soon as possible after electroplating in order to relieve hydrogen embrittlement.

High-alloy steels (including stainless steels) require very thorough cleaning and etching, following the same procedure as described above, but care is necessary to ensure that too much attack on chromium-containing alloys does not occur in the anodic cleaner.

It is not sufficient, however, after the sulphuric acid etch, simply to rinse and then plate, as an oxide film develops very rapidly once the etch solution is removed from the surface. The difficulty is overcome by the use of a 'strike' solution. This is a plating solution that is strongly acid and contains a rather low concentration of depositable metal ions. When the work is made cathodic in this solution, copious evolution of hydrogen occurs. This, in combination with the acid present, rapidly removes any residual oxide film; meanwhile metal is slowly deposited on the freshly exposed surface.

After a few minutes, the work can then be transferred directly, without rinsing, to the main plating tank. The most popular strike solutions, for use before plating in a nickel bath, contain either nickel chloride and hydrochloric acid or nickel sulphate and sulphuric acid.

Copper-base materials

The following sequence is commonly used to prepare brass for plating: solvent degrease, cathodic clean, brief anodic clean, rinse, hydrochloric acid dip, rinse. A somewhat more elaborate sequence may be followed when plating for engineering applications. For example, the work may be scrubbed with pumice after cathodic cleaning, and the hydrochloric acid dip replaced either by a nitric acid dip or by a brief anodic treatment in acid ammonium citrate solution. Some prefer to carry out an anodic etch in a cool solution of sodium hydroxide containing a little cyanide, and then to dip in dilute sulphuric acid to remove any stains.

Reference should be made to specialist texts for pretreatment sequences for alloys such as beryllium copper.

Zinc-base materials

The alloy used in zinc-based die castings contains about 4 % aluminium. The castings are often plated with decorative coatings of nickel plus chromium, but an undercoat of copper is almost always present.

In preparing zinc die castings for plating, it must be borne in mind that the alloy is readily attacked by both acid and alkaline solutions. As much as possible of surface contamination is removed by solvent cleaning, then the castings are immersed in an alkaline soak cleaner and subsequently anodically cleaned for a brief period, and rinsed. Only mild cleaners should be used, specially formulated to avoid attack on the basis metal. A very mild acid dip follows, followed by thorough rinsing.

A copper coating about 10 μm thick is then applied before nickel and chromium plating. The copper may be deposited in one layer from a cyanide solution, but sometimes only 3-5 μm is applied from this solution (the minimum necessary to protect the basis metal) and then the coating is built up to the total thickness required in a pyrophosphate or levelling acid sulphate solution.

Aluminium and aluminium alloys

Aluminium and its alloys rapidly form tenacious oxide films to which electroplated coatings are unlikely to adhere. This is the main consideration to bear in mind in devising a pretreatment sequence. Other factors are the ease with which the alloys are attacked by various plating solutions and the variations in electrochemical behaviour arising from the presence of different alloying constituents.

Electroplating of aluminium alloys has been accomplished successfully by various methods, but the one that has best stood the test of time is the zincate process. A zincate solution is made up by dissolving zinc oxide in sodium hydroxide solution. When an aluminium alloy is immersed in this, a replacement coating forms, i.e. aluminium is dissolved and an equivalent amount of zinc is deposited. As this coating may be thick and highly porous, it is not unusual to dissolve it in nitric acid solution then repeat the process, when the zinc coating obtained will tend to be more uniform and compact.

This is known as the double zincate treatment. Subsequent processing follows the

pattern described above for plating zinc alloys, i.e. usually copper plate before finishing with nickel plus chromium or other top coat.

Various modifications to the zincate process have been described, some adapted to the plating of particular alloys. One proprietary process based on a dilute zincate solution containing additions of other metals, such as copper and nickel, in complex form, gives a coating that can be plated direct with nickel and various other metals; it can be used without modification on a wide variety of alloys.

Another well established proprietary process employs a replacement deposit of tin instead of zinc and is preferably followed by a bronze undercoat.

A complete preplating sequence comprises the following steps (plus rinses): 1) degrease (if alkaline soak cleaner is employed, make sure it is free from caustic alkali and silicate); 2) cathodic clean (again in solution appropriate for aluminium); 3) dip in strong nitric acid solution or, for some alloys, a nitric-hydrofluoric acid mixture; 4) immerse in the zincate or similar solution (it may be advisable to strip the first coating in nitric acid solution and apply a second in a shorter immersion time); 5) proceed to first electroplating stage.

Non-metallic materials, including plastics

It is possible to electroplate almost any kind of non-conducting solid article, after first applying a conductive coating. If the material is porous or likely to be attacked by the processing solutions, it will be necessary to protect it with an impermeable film.

Sometimes a conductive paint performs both functions or, alternatively, an article may be encapsulated in a lacquer film and subsequently metallized by a chemical spray or immersion method. When plating begins on such a thin conductive film it is essential to maintain a low current density, but the current can be increased progressively as the deposit gets thicker and thicker.

Coatings applied in this way have limited adhesion to the substrate, and so must form a complete envelope if the integrity of the coated article is to be preserved. In the case of certain materials, e.g. plastics, the adhesion can be improved by roughening the surface before plating, using abrasive blasting or tumbling. A break-through occurred about 20 years ago when it was found that truly adherent deposits could be applied to a particular grade of ASS (acrylonitrile-butadiene-styrene). The necessary pretreatment involves an etch in chromic-sulphuric acid solution. This dissolves polybutadiene globules at the surface of the plastic leaving tiny holes that provide secure anchoring points for subsequently applied metal coatings; possibly it also, by oxidising carbon-to-carbon double bonds in the polymer, lays a basis for chemical links to be established. A similar degree of adhesion can nowadays be attained on other types of plastic as well, including polypropylene.

While some plastics may require solvent treatment, alkaline clean and acid dip, these can usually be omitted on ABS or polypropylene. These go straight into the etch or conditioning solution and then, after a rinse or acid dip, into the activator. The activator, which may comprise only one or more stages, is designed to achieve a uniform distribution of tiny palladium or copper nuclei, which will act as catalyst in the

subsequent electroless copper or nickel plating stage - these electroless solutions are slightly alkaline and generally operated at room temperature. Subsequent processing depends on the application; a possible sequence would be: bright, levelling acid or pyrophosphate copper (starting at low current density, as explained above), bright nickel, chromium.

4. Specifying and purchasing electroplating

Requirements of customer and supplier

If a satisfactory electroplating service is to be provided, the customer and the supplier must be clear about each other's requirements. They should reach an agreement, which would be best expressed in terms of a formal specification, but should in any case be explicit.

The information required by the plating contractor will include the following:

- 1) the material of construction of the component;
- 2) its initial surface condition;
- 3) its dimensions and tolerances;
- 4) the significant surface (i.e. the part of the surface that must be covered by the coating and any part that must not be covered - it is preferable to let the contractor decide whether he will plate non-significant areas as well)
- 5) the type(s) of coating required;
- 6) the thickness(es) of coating to be applied (usually in terms of minimum, or sometimes average, thickness; an upper limit may occasionally be imposed);
- 7) any pre- or post-plating treatments necessary, in particular, to avoid hydrogen embrittlement;
- 8) the appearance demanded and an indication of the positions where contact marks will be acceptable;
- 9) batch size and frequency;
- 10) containers to be used for transport;
- 11) inspection procedures;
- 12) performance testing required.

It is best if the information required in items 1) to 7) is stated unambiguously on an engineering drawing. Other methods are possible, however, e.g. the use of samples, which is often the only way of dealing adequately with item 8), as the judgment of appearance is manifestly subjective. An accurate estimate, under 9), of batch size and frequency enables the contractor to assign the appropriate capacity (plant, labour, etc.) and to make production engineering decisions regarding jiggling arrangements, work handling methods, etc. Note in relation to item 11) that inspection of incoming work by the contractor is rarely justified - it should be the responsibility of the customer to ensure that the components supplied are suitable for plating. Performance tests required under item 12) may take a period of time to complete, thus occasioning some delay in the release of the plated components.

The information required by the customer includes:

- 1) the price for processing components and any variation dependent on batch size (costs are relatively high on small batches);
- 2) any supplement required to cover the cost of special plant or jigs;
- 3) the delivery time for specified batch sizes;
- 4) elapsed time (including trials) before first commercial batch can be processed.

Pricing

It is impossible to give firm guidelines on prices, but an indication of the basis on which prices are calculated can be obtained from the following breakdown of a typical electroplating company's costs:

Wages, salaries and on-costs	40 - 50%
Energy	15 - 20%
Depreciation, rates, insurance, post, etc	15 - 20%
Plating materials	10 - 20%
Transport	5 -10%

Clearly, excepting the case of precious metal plating, materials costs are low compared with most manufacturing industries; employment and energy costs, in particular, are relatively high. To recover his costs a plating contractor will often base the price on the total processing time, a combination of handling and machine time. Factors to bear in mind are:

- 1) Machine time usually depends on the duration of the plating operation, which is proportional to the thickness of the deposit.
- 2) Jigging requires individual handling, in contrast to bulk processing in barrels.
- 3) The area and shape of a component determine the space it occupies in the plant.
- 4) The degree of special skill or ancillary work required is often significant.

Conditions of quotation and sale

Although a plater's legal relationship with his client is the same as any other contractor's, certain points may cause difficulties:

- 1) The specification is often not explicit, and problems may arise because enquiries and quotations are informal and short cuts are taken to save time; in these circumstances it is unlikely that all the factors mentioned above will be taken care of.
- 2) Good records and frequent reconciliation are necessary if quantity discrepancies are to be avoided. It should be laid down if the plater is required to count components on receipt, as otherwise he may not do so.
- 3) An agreed sample is desirable as a criterion of appearance. It must be borne in mind, however, that exact uniformity of finish and colour is not usually possible, and some coatings change in appearance during storage.
- 4) Because the component value is high when the plating stage is reached, irrecoverable rejects are costly. Many platers have a written clause limiting their liability to three times the plating price of lost components, after allowing for a 2 1/2% rejection rate on the whole order.

Example:

Order size 1000, losses 100, plating price 10p each Permitted rejects at 2 1/2 % of 1000 is 25 Compensation paid on 75 rejects is $75 \times 3 \times 10p = \text{£}22.50$.

1. Sources of further information

Books

General

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Journals

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British Corrosion Journal, The Metals Society, 1 Carlton House Terrace, London SW14 SOB.

Corrosion Protection and Control, Scientific Surveys Ltd., 4 Burke's Parade, Beaconsfield, Bucks.

Finishing, Wheatland Journals Ltd., Penn House, Penn Place, Rickmansworth, Herts W03 1SN.

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Metal Finishing Abstracts, Finishing Publications Ltd., 28 High Street, Teddington TW118EW.

Metal Finishing Plant & Processes, Finishing Publications Ltd., 28 High Street, Teddington TW11 8EW

Plating and Surface Finishing, American Electroplaters' Society Inc., 1201 Louisiana Ave., Winter Park. EL 32789, USA

Product Finishing, Sawell Publications Ltd., 127 Stanstead Road, London SE23 1JE.

Products Finishing, Gardener Pubs, Inc., 600 Main Street, Cincinnati 2, Ohio, USA

Surface Technology, Elsevier Sequoia S.A, P.O. Box 851, 1001 Lausanne 1, Switzerland.

Transactions of the Institute of Metal Finishing, Exeter House, 48 Holloway Head, Birmingham B11NQ.

Standards

The following are published by the British Standards Institution, British Standards House, 2 Park 51, London W1 Y 4AA. Where there is a corresponding document issued by the International Organization for Standardization (ISO), its number is given in brackets after the title.

Nickel and chromium

BS 1224 Electroplated coatings of nickel and chromium (ISO 1456-8)

BS 4601 Electroplated coatings of nickel plus chromium on plastics materials.

BS 4641 Electroplated coatings of chromium for engineering purposes.

BS 4758 Electroplated coatings of nickel for engineering purposes.

Standards are not yet available but are being prepared for electroless nickel coatings, for engineering and for decorative applications, and for nickel/iron coatings.

Precious metals

BS 2816 Electroplated coatings of silver for engineering purposes.

BS 4290 Electroplated coatings of silver for decorative purposes.

BS 4292 Electroplated coatings of gold and gold alloy.

Tin and its alloys

BS 1872 Electroplated coating of tin (ISO 2093)

BS 3597 Electroplated coatings of 65/35 tin-nickel alloy (ISO 2179)

BS 6137 Electroplated coatings of tin-lead alloys

Zinc and cadmium

BS 1706 Electroplated coatings of cadmium and zinc on iron and steel (ISO 2081-2).

Threaded components

- BS 3382 Electroplated coatings on threaded components.
- Part 1 Cadmium on steel components.
- Part 2 Zinc on steel components.
- Part 3 Nickel or nickel plus chromium on steel components.
- Part 4 Nickel or nickel plus chromium on copper and copper alloy (including brass) components.
- Part 5 Tin on copper and copper alloy (including brass) components.
- Part 6 Silver on copper and copper alloy (including brass) components.
- Part 7 Thicker platings for threaded components.

Test methods

- BS 5411 Methods of test for metallic and related coatings.
- Part 1 Definitions and conventions concerning the measurement of thickness (ISO 2064).
- Part 2 Review of methods for the measurement of thickness (ISO 3882).
- Part 3 Eddy-current method for measurement of coating thickness of nonconductive coatings on non-magnetic basis metals (ISO 2360).
- Part 4 Coulometric method for the measurement of coating thickness (ISO 2177).
- Part 5 Measurement of the local thickness of metal and oxide coatings by the microscopical examination of cross sections (ISO 1463).
- Part 6 Vickers and Knoop microhardness tests (ISO 5416)
- Part 7 Profilometric method for measurement of coating thickness (ISO 4518)
- Part 8 Measurement of coating thickness of metallic coatings: X-ray spectrometric methods (ISO 3497)
- Part 9 Measurement of coating thickness of electro-deposited nickel coatings on magnetic and non-magnetic substrates: magnetic method (ISO 2361).
- Part 10 Review of methods available for testing adhesion of electrodeposited and chemically deposited metallic coatings on metallic substrates (ISO 2819/1).

- Part 11 Measurement of coating thickness of non-magnetic metallic and vitreous or porcelain enamel coatings on magnetic basis metals: magnetic method (ISO 2178).
- Part 12 Beta back scatter method for measurement of thickness (ISO 3543)
- Part 13 Chromate conversion coatings on zinc and cadmium (ISO 3613)
- Part 14 Gravimetric method for the determination of coating mass per unit area of conversion coatings on metallic materials (ISO 3892)

BS 5466 Methods for corrosion testing of metallic coatings.

- Part 1 Neutral salt spray test (NSS test) (ISO 3768).
 - Part 2 Acetic acid salt spray test (ASS test) (ISO 3769).
 - Part 3 Copper-accelerated acetic acid salt spray test (CASS test) (ISO 3770).
 - Part 4 Thioacetamide test (TAA test) (ISO 4538).
 - Part 5 Corrodokote test (CORR test) (ISO 4541).
 - Part 6 Rating of results of corrosion tests on electroplated coatings cathodic to the substrate (ISO 4540)
 - Part 7 Guidance on stationary outdoor exposure corrosion tests (ISO 4542)
- BS 3745 The evaluation of results of accelerated corrosion tests on metallic coatings (ISO 1462).

Miscellaneous

CP 3012 Cleaning and preparation of metal surfaces.

BS 4479 Recommendations for the design of metal articles that are to be coated.

BS 6001 Sampling procedures and table for inspection by attributes.

BS 6041 Method of sampling of electrodeposited metallic coatings and related finishes.

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