

ELECTROPLATING EXPLAINED

Based on information from "Electroplating - A Guide for Designers and Engineers" available from the IMF U.K. and leaflets on plating processes published by the Surface Engineering Association U.K. as well as additional material from the "Electroplating - Theory & Practice" the SAMFA Training Manual.

DEFINITION

Electroplating is a method of using an electric current to deposit a thin layer of metal over another from a solution containing a dissolved salt of the selected metal.

BASIC ELECTROCHEMISTRY

In order for this to happen we have to create a closed circuit, an electrolytic cell, where each element in the system is of equal importance. These components are:

- * A source of adjustable direct current, most commonly a transformer-rectifier with positive and negative terminals rigged for cable or busbar connections. In the trade this piece of equipment is usually referred to by its short name – the "rectifier".

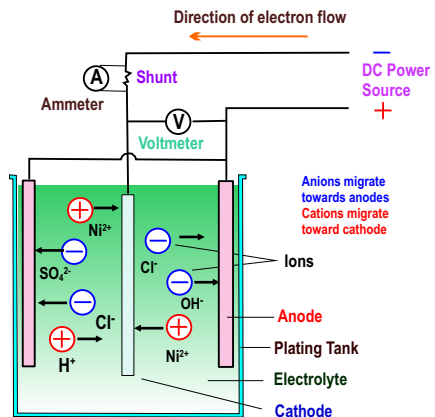


Figure 1 - Electrolytic Cell

- * The electrodes that can be described as follows:
 - An anode connected to the positive terminal; the anode is generally composed of the material that we want to deposit. Copper in the case of copper plating, nickel in the case of nickel plating and so on. It is also possible to plate using "inert" anodes like carbon rods in certain cases.
 - A cathode connected to the negative terminal; the cathode is the component on which we intend to deposit the metal. In the plating workshop this is commonly referred to as the "work-piece", or just the "work" or the "job".
- * A tank to house the plating solution containing the appropriate dissolved

metal bearing salts. The correct term for this solution is the “electrolyte” but in the plating shop it is generally simply referred to as the “solution”.

When the electrodes are immersed in the plating solution the circuit is completed and we have all the elements of the electrolytic cell in place. All that remains is to turn on the power from the rectifier, and deliver an appropriate amount of direct current to the system. This causes metal ions to dissolve from the anode and enter the solution. Metal ions are really atoms short of one or more electrons. Metal ions already in the solution, originally provided by the dissolved salt, migrate towards the cathode (the work-piece) where they collect electrons and deposit as pure metal again. These ions are replaced by those coming off the anode thus keeping the solution more or less in balance.

Inert anodes, mentioned earlier, do not contribute metal ions to the solution. A common example of this is in chrome plating where the anodes are not fashioned from chrome, but rather from lead or a lead alloy. The lead conducts electricity into the bath which causes electrolysis to occur and chrome metal ions in the solution migrate to the cathode to deposit as chrome metal. However, as no new chrome ions can be provided by the anodes, these ions have to be constantly replenished via additions of the compound commonly known as chromic acid (more correctly chromium (vi) oxide).

The metal bearing salts that are used to provide the ions required are produced in chemical reactions such as those resulting from dissolving pure metal into acid, alkaline or cyanide solutions amongst others. Copper sulphate, for instance, may be produced by dissolving copper granules into warm sulphuric acid. In this case the hydrogen in the acid is driven off and replaced by the copper. The resultant precipitate exists as a lattice of copper and sulphate ions. In its dry state this metal compound awaits introduction into water when on dissolving the ions will dissociate freeing up copper cations (Cu^{2+}) and sulphate anions (SO_4^{2-})

DEPOSITION SPEED

The English physicist Michael Faraday (1791 – 1867) provided us with the important rules that govern electro-deposition. He showed that the amount of metal deposited at the cathode and the amount dissolved at the anode are directly proportionate to the quantity of electricity passed – in other words to the current and time period of the electro-deposition.

Thanks to his efforts and another of his rules, Faraday's Constant, we can

calculate the theoretical deposit weight of any metal that we are plating based on its atomic weight and the number of electrons involved in the electrochemical reaction. [Atoms gain and lose electrons during the plating process as they do in all chemical reactions – this causes them to become either positive or negative ions]

CATHODE EFFICIENCY

This leads us to a discussion on “cathode efficiency”. Plating solutions that deliver the full theoretical weight of metal within a specific current/time relationship [the Faraday – 26.8 ampere hours] are said to have 100% cathode efficiency. Of all the metals deposited, only silver deposits match up to the theory. All other metals have cathode efficiencies ranging downwards to as low as 12%. This is because hydrogen which is generated during the plating process also migrates toward the cathode and is released or absorbed there. So in the case of a plating solution that proves to have 80% cathode efficiency, the balance of the “deposit” is made up of 20% hydrogen.

Low current efficiency describes why chrome solutions gas furiously during plating

Low cathode efficiency explains why chrome solutions gas so furiously during plating, giving rise to large amounts of hazardous aerosol. This has to be dealt with through one or another mechanism, both to protect workers and conserve the solution. It also explains “gas-trapping” where hydrogen gathers in awkward low current density areas blocking the passage of metal ions. Much work has been done on proprietary additives

to help overcome this problem in chrome plating and modern additives can double the inherent cathode efficiency.

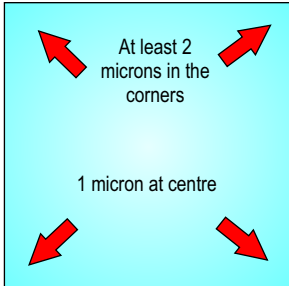
HYDROGEN EMBRITTLEMENT

Most of this hydrogen bubbling away vigorously at the cathode is liberated into the atmosphere. But some of it is absorbed at the cathode – into the work-piece. If this happens to be a hardened high-carbon steel component, the entry of this hydrogen into the structure of the metal can lead to what is known as “hydrogen embrittlement”. As the hydrogen rearranges itself within the structure, the internal stresses set up are often enough to cause a part to fracture with no external force being applied. Even if the part does not fracture on its own, it may easily do so with the application of minimal external stress. It is easy to see the

potential for catastrophic consequences in safety critical components.

Potential hydrogen embrittlement can be reversed by heat treatment immediately after plating to drive the hydrogen out before it can cause any harm. If it is left for any length of time, the damage becomes irreversible.

METAL DISTRIBUTION



Even on a flat sheet the variation will not be less than 2:1

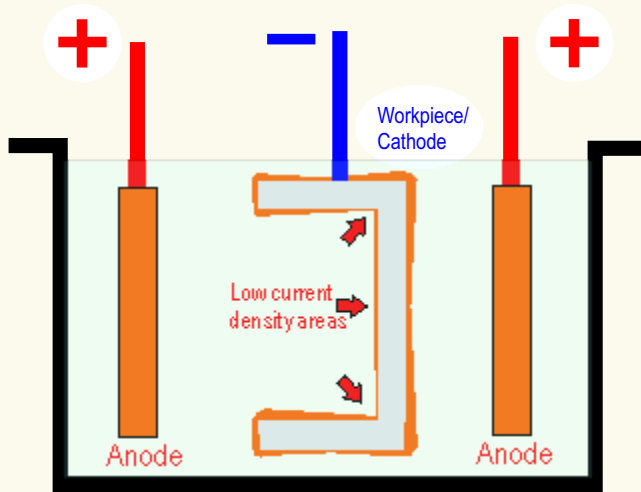
When a current is applied to a load of work the distribution of current is not uniform over the whole area. If an area of 1 square decimetre is plated at 4 amps the average current density is 4 amps/dm² but the true density at any one spot (the local current density) may vary widely. The actual variation will depend on the shape of the part and the arrangement of the anodes; even with the simplest of shapes – a flat sheet – the variation will be not less than 2:1. It will be greater with more difficult shapes such as a tube where little or no

current will reach the inside. By using specially designed anodes the current distribution can be improved. Such conforming anodes are discussed in the paragraphs ahead.

Just as there is a preferred range of cathode current densities for each plating solution so there is a correct range for anode current density. Too high a density can cause the formation on the anode of an insulating film (usually oxide), which can lower the current and cause other troubles. Too low a density is also to be avoided.

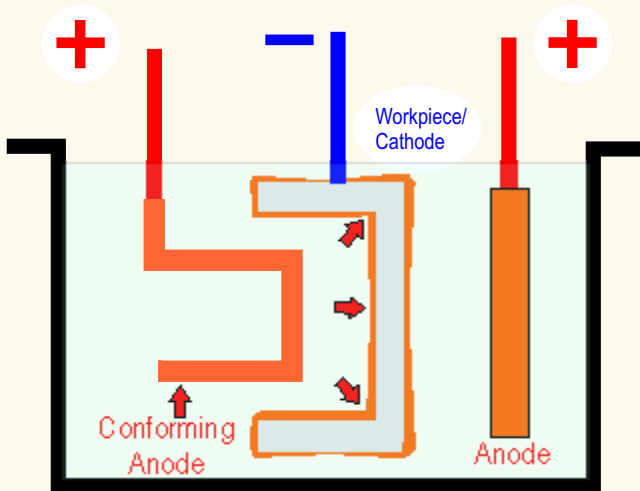
THROWING POWER

The throwing power of a plating solution is a measure of the ability of that solution to plate to a uniform thickness over a cathode of irregular shape. Remember that the work being plated is the cathode – so an irregularly shaped cathode refers to an awkwardly shaped piece that has to be processed. If such a cathode (or piece of work) is plated to a uniform thickness over its entire area the solution would be said to have a perfect throwing power. If it plated only on those areas nearest to the anodes then the solution has a very poor throwing power. All plating solutions fall somewhere between these two extremes and can be classified as “good”, “medium” or “poor”.



Arrows highlight the low current density areas in a channel shaped component. The plated deposit is represented by the orange area encapsulating the work piece. Note that the thickness in this region is considerably less than elsewhere and is directly linked to the ability of the solution to “throw” into such a recessed area.

Using a Conforming Anode

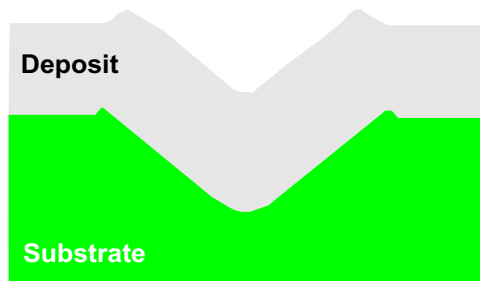


To improve throw, a conforming anode may be fashioned to bring the anode in closer proximity to the low current density areas. In this manner it is possible to considerably improve the deposit thickness in areas where solution throw is poor.

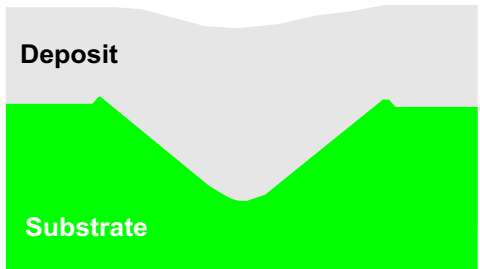
It is always desirable to secure an even thickness of plating – or uniform metal distribution. The metal distribution depends mainly on the distribution of current, which we know to be uneven; there will, for this reason, be a corresponding uneven thickness of plating. Any measure taken to make for better current distribution will also yield a more uniform plating thickness. One such method would be to construct a conforming anode; that is an anode that is constructed to follow the shape of the piece being plated. Where the component has a hollow, the conforming anode has a projection into the hollow, always maintaining a safe distance from the surface to avoid burning.

LEVELLING

In the preceding paragraph we discussed what is really more properly defined as macro throwing power – the capacity of a particular solution to evenly distribute over some distance. Some solutions are better at this than others – cyanide copper plating solutions have reasonably good throwing power whilst basic acid copper plating solutions have notably poor throwing power. There is however a secondary and equally important consideration and that is the ability of a solution to plate into the bottom of shallow scratches and fine grooves (micro valleys) with the same coverage as on the metal surface. Here the difference between the high and low current density areas is measured in microns. This is the type of surface condition that may be encountered as a result of blasting, grinding, polishing, drawing processes or extrusion. An anomaly is that solutions with good macro throwing power don't necessarily exhibit good micro throwing power and those with good micro throwing power (like acid copper and acid nickel) don't have good natural macro throwing power.



Deposit from a basic solution with inherently good micro-throw properties and excluding additives.



Deposit from a basic solution with inherently good micro-throw properties and making use of specialised additives to force levelling.

Solutions that do have good micro throwing power can be adapted to perform levelling. This is achieved by the addition of organic additives to the plating system. These are chemicals that preferentially congregate around the “high” current density area, the “top bank” of the crevice or groove and have the effect of stifling the deposit in that area, forcing the deposition downwards into the crevice. The net effect is that the plating in the crevice proceeds to build up more quickly than the plating on the surface until all the crevices are levelled. The whole surface is then more level or even than before the commencement of the plating process.

However, a solution that exhibits good micro throwing power is not necessarily always used solely to promote levelling. The ability of the solution to evenly deposit in micro recesses and on micro peaks ensures even deposits of low porosity. This is useful in producing a barrier coat that will prevent diffusion into the base metal, important for instance when gold plating. Additive free nickels are sometimes used for this purpose.

USES OF PLATING

According to figures from the Corrosion Institute of Southern Africa, this country suffers losses equal to 4% of GDP annually due to corrosion. Figures from 2005 record South Africa as having generated GDP of about R1500 billion. At 4% this means that corrosion cost this country about R60 billion during 2005. These figures accentuate the significance and necessity of surface finishing.

Every metal has its own properties; these individual properties may be good or bad, important or unimportant. No one metal has only good properties; all are mixtures of the good and the bad. Take steel as an example. It has far more good properties than bad and this is why it is so widely used. It is plentiful and



Zinc plated tow balls

inexpensive, it is strong and hard and has a high melting point; it is workable – it can be rolled into sheets or drawn into wire; - it can be machined to intricate shapes or cast into enormous girders. These are good properties; no other metal has so many. Its chief bad property is its poor resistance to corrosion causing it to rust severely in damp atmospheres and to become tarnished even in good atmospheres.

Zinc has very different properties. It is more expensive; it is soft and melts at a low temperature. But it does resist corrosion far better than does steel. A thin coating of zinc applied to the surface of steel – as by electroplating – gives to the steel much of the corrosion resistance of the zinc. Thus, a zinc plated steel part combines the good properties of the two metals. This then is the major reason for electroplating. It enables the engineer to combine the good mechanical properties of one metal with the desirable surface properties of another. Electroplating offers the engineer a wide choice. If the part is steel, and his only problem is corrosion, he may choose to zinc plate; but if zinc is too soft or if he wants a better appearance he can specify nickel-chrome. He may want good electrical performance and can be offered copper or silver. If the part is for the food industry it can be tin-plated.

Generally one could say that there are two major reasons for electroplating – either decorative or functional.

Decorative electroplating is used where there is a demand for an attractive outer finish although this layer performs no technical function. The plastic trim on a motor car or the brass decorative fittings on a wardrobe for example do not need to be protected from corrosion. Plated surfaces in copper/nickel/chrome, silver or gold become pure design elements in such applications.



Electroplating can meet several requirements – all at the same time. An electrodeposited coating is the perfect solution when bathroom fittings or spectacle frames need to be permanently protected against corrosion and be attractive at the same time. The choices range from copper/nickel/chrome to gold, bronze, etc.

An improvement in appearance is often simply an added bonus when the original requirement was predominantly functionality. A steel storage rack in a warehouse might be zinc plated to stop corrosion – however the bright zinc coating also enhances the appeal of the product and helps influence the warehouse manager in his choice of racking systems.

Electroplating provides the perfect solution for every taste and every stylistic preference. It ensures the desired finishing for everything from shiny, chrome-

plated tubular furniture to matt chrome-plated lamp sockets, copper-plated antique look bowls, silver plated candlesticks or gold plated fountain pens.



Silver plated cutlery is proof that electroplated items are often less expensive but every bit as useful. For example, they have the same antibacterial effect as their solid silver counterparts. A 12-part silver plated set requires only about 70 – 90 grams of silver, while the solid version requires several kilograms.

There are countless applications for electrodeposited surfaces in every conceivable area of engineering. Precisely defined requirements of components and finished items determine the choice of the right layer or layer system. Electroplating allows us to use the best qualities of different metals and make them work together in the best possible way.

Designers and production planners can choose the technically ideal and most economical surface from a wide range of different coatings. Zinc-plating sometimes combined with chromating and sealing, zinc alloy layers, layer system of copper/nickel/chrome, chemical nickel plating, hard chrome plating, tin-plating, silver plating, gold plating – these are all options in functional electroplating. The hard chrome engineering industry is an example of one that can save a client vast amounts of money through building up worn components and re-machining rather than replacement with new parts.

Requirements for reliable protection from corrosion and wear combined with a perfect finish are found in many product areas including the motor industry, the lighting and furniture industries, household appliances, gifts and jewellery.

Printed circuit boards with gold plated electronic connectors carry out a variety of important functions, for example, in your telephone, television, washing machine or computer – or when a satellite is launched into outer space. Printed circuit board production, an important aspect of electroplating, continues to gain importance in our technically advanced world. Hundreds of metal conductor strips are deposited onto the smallest surfaces using a multi-step electroplating process. The



front and back of a circuit board are connected through tiny electroplated holes. Equipped with electronic components, circuit boards are indispensable to today's technology.

For example, circuit boards not only ensure that your camera's exposure meter functions properly, they also help jumbo jets come in for a safe landing. They also play a large part in managing the under-hood functions of today's motor cars and play a part in reducing emissions.

ELECTROPLATING SAVES SCARCE RESOURCES

Today the focus is on preserving raw materials and natural resources, protecting the environment and saving energy wherever possible. Electroplating is a step in the right direction. Extremely thin layers of just a few microns are deposited onto the base materials, so valuable resources are used sparingly and only in places where they are really needed. The chemical processes involved in electroplating have also been rapidly developed and adapted to modern demands. Energy-saving automation, closed water circuits and highly advanced waste water treatment and resource recovery systems now represent the state of the art.

ELECTROFORMING

Taking the electroplating process a step further leads us to electroforming.

Electroforming is the process by which articles are manufactured by building up metal through electrodeposition onto a suitable mandrel which is removed. Nickel is a popular choice for this operation, but copper also has applications.

Electroforming has a number of features that make it a viable production process for specific applications. These include:

Accurate reproduction of fine surface detail

Example: the electroforming of stampers for the production of compact discs

Duplication of surface textures

Example: dies to produce wood grain or leather patterns

High degree of dimensional stability

Example: precision components

Ability to electroform shapes that are difficult and costly to produce by any other

method of fabrication.

Example: rotary printing screens

Nickel electroforming is used to produce tools, radar wave guides, spray masks and a wide range of components that would be difficult or costly to fabricate by any other means. Additionally, nickel electroforming is used in the production of foils and mesh products. This is a specialised procedure involving continuous deposition onto a rotating drum.

DESIGN CONSIDERATIONS

Earlier on it was explained 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 surprising 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 depth and length may be twice the thickness achieved at the centre of each face. The diagrams on the following page give an idea of how coating thickness varies over certain typical shapes.

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's not much use however offering a cyanide copper deposit where a hard chromium deposit is required.

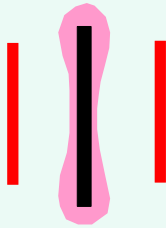
The principal ordinary means are: choice of appropriate anode size and position, with the use of conforming anodes where possible; and judicious arrangement of components in relation to each other to achieve a degree of mutual shielding or compensation. These procedures can be quite effective.

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

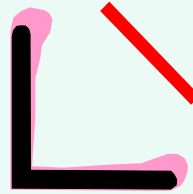
Design Considerations

Coating Distribution

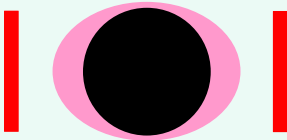
It was explained why electroplated deposits tend to vary to a greater or lesser degree over the surface of an article. Deep recesses present the biggest problem, but distribution over even apparently simple shapes may be surprisingly uneven unless special precautions are taken. All edges and corners attract more than their fair share of current. As a rough guide, the average coating thickness of nickel on a flat rectangular sheet may be twice the thickness at the edges as is achieved at the centre of the face. The illustration below shows how a coating may vary over various typical shapes.



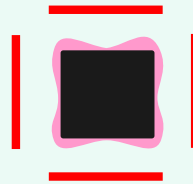
Thickening of deposit at edges of flat sheet



Thickening of deposit at edges and thin deposit in corner of right angled shape



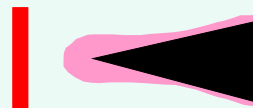
Ovality of Deposit on Circular Section



Build up of Corners on Square Section



Thin deposit in centre of Concave Surface



Build up of deposit on a Point

Substrate

Deposit

Anode

widely used as might be expected. Connected to the positive terminal of the power supply or sometimes to 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 position 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 or protective coatings.

It is in the manufacturers own interest to do what he can to help the plater achieve a reasonably uniform thickness by observing simple design principles. There is a British Standard, BS 4479, that gives appropriate recommendations. The diagrams on the next page are taken from the section dealing with electroplated coatings. The diagrams are not, of course, rigid guidelines, but merely illustrative examples.

RINSING AND DRAINAGE

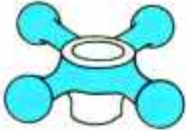
It is easy to appreciate the importance of good drainage if one considers the many stages involved in a typical plating operation. To zinc plate and passivate mild steel components a sequence similar to the following is necessary:

- a) soak clean in hot alkali
- b) electrolytically 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

Design Considerations

Coating Distribution (continued)

AVOID



Protuberances draw current preferentially

PREFER



AVOID

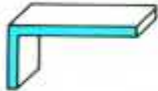


Ribs should be smooth in section and spaced as widely as possible

PREFER

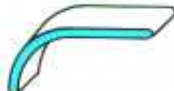


AVOID



Corners should have a radius of at least 1mm

PREFER



AVOID



Corners and edges of indentations should be rounded to a radius of at least a quarter of their depth

PREFER



AVOID



Edges should be smoothed as much as possible

PREFER



AVOID



Inside curved surfaces should have a minimum radius of 12.5mm

PREFER



AVOID



Space fins as widely as possible and round the edges

PREFER



AVOID



Eliminate sharp edges and corners of slots

PREFER



AVOID



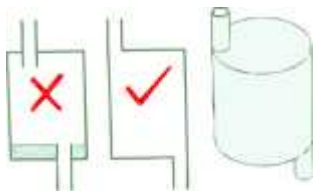
If blind holes are essential they should be shallow with well rounded corners and edges

PREFER



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.



**Avoid pockets & blind holes
in which solution can be trapped**

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 minimising 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.



A plated finish draws attention to any imperfections that may exist

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 scrutinised 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

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 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 loaded and operated.

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 **ATOTECH**

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).

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.

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.

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



Typical jiggling room in an electroplating jobbing shop

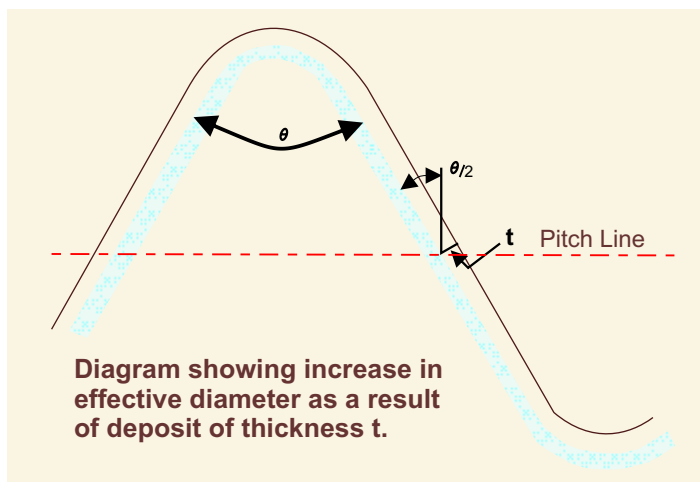


Plating barrel on an auto line lowering into the tank

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 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. See diagram below. 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.



Tangled parts



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

1. 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 the practice is often acceptable, except where automatic assembly methods are used.
2. Make a special allowance on thread dimensions. External threads may be produced undersize or internal threads oversize to leave room for

the specified coating.

3. 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.
4. 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.
5. 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, conductive tapes made of aluminium or copper foil are sometimes used. Tapes of this type are in electrical contact with the cathode; they therefore receive a deposit them-

selves 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.

Purpose built jigs incorporating silicone rubber masks have also been used for selective plating.

BRUSH PLATING

Gold and most other metals may also be deposited by the brush plating system. The brush plating electrode resembles a felt tipped pen. The felt reservoir in the body of the pen, instead of being saturated with ink, is saturated with a concentrated plating solution. The anode connection could be described as a conductive pin driven vertically through the body of the pen, so that it makes extensive contact with the saturated felt. When the work for plating is connected to the negative pole of the rectifier, and the saturated felt tip of the electrode is brushed over the metal surface, the circuit is completed and the positively charged metal ions in the felt migrate to the cathode and are deposited.

Brush plating is useful for plating surfaces that are simply impractical or too costly to consider for treatment in conventional facilities. The process can be carried out on site, far from a plating shop and using low volumes of plating solution. If necessary, a battery or generator may be used for current. In large applications the "pen" is substituted for something more resembling a roller. In modern times, complete cathedral domes have been plated using this method.

CONTINUOUS PLATING

Steel and other metals or alloys, in the form of sheet or strip, are continuously electroplated in highly specialised 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 precoated metal by normal fabrication procedures and frequently require no further electroplating operations. The best known example is the production of tinfoil 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 of 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-lead¹. 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

A comprehensive reference chart providing information about a variety of metal coatings and alloys and the areas in which they are used has been included as a separate item together with this publication.

PREPARATION FOR PLATING

GENERAL

The nature of the base 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 later, but it is convenient first to review the general range of pre-treatment processes.

Cleaning processes fall into two broad classes, alkaline and solvent-based. Alkaline cleaning is virtually essential and although there are advantages to solvent cleaning, environmental considerations are putting pressure on

¹ Tin-lead coatings will give way to lead free coatings under compliance with European RoHS legislation. [Restriction of Hazardous Substances]

operators to curtail their use.

Organic solvents, such as trichloroethylene and perchloroethylene, are still being used hot in vapour or liquid-vapour degreasers, but over time these installations will come under increasing scrutiny by authorities. 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 may be recycled by the supplier by re-distillation and with the addition of inhibitors.

In the same way, emulsifiable solvents that have been used as soak cleaners also have been largely phased out due to the negative environmental impacts. These solvents contain surface active agents, which cause them to be emulsified in a subsequent water rinse and so removed along with the soil. Unfortunately, the solvents leaving the factory as effluent continue to cause problems further down the line.

The most satisfactory apparent substitute for solvent cleaning at this stage is ultrasonic cleaning, making use of a suitably modified alkaline cleaning formulation.

Alkaline cleaners may contain sodium hydroxide and alkaline salts such as metasilicate, carbonate, tripolyphosphate or hexametaphosphate, as well as powerful wetting and sequestering agents. The sodium hydroxide may be omitted, however, where only a light-duty cleaner is required. Cyanides, once included in some heavy duty formulations, are also being excluded as the industry seeks to rid itself of toxic products. The cleaners are used hot, the work being immersed for anything between one and twenty minutes depending on a permutation of variables such as the surface contamination, the solution formulation, available time, etc. Mechanical effects such as movement of the parts, the solution or both help to accelerate the process.

Further acceleration can be achieved 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 (the work-piece) 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. Brass qualifies as such a material.

Cleaning is usually followed by a rinse in water, then a dip in a dilute hydrochloric or sulphuric acid solution, followed by a further rinse, before entering the plating bath. The function of the acid dip is to neutralise 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 strongly alkaline soak cleaner, pickle in strong acid, then clean again in a separate alkaline cleaner, usually under anodic conditions. After rinsing, the parts are given a brief dip in dilute acid solution, then rinsed twice before being placed in the plating tank. Where there is any question of adhesion being compromised, for example through potential incomplete removal of welding scale an anodic etch in sulphuric acid solution may replace or complement the acid dip. A similar procedure is used for cast iron, but it is important in this case to etch a high current density for only a short time. In a manual operation it may then be necessary to brush away any loose carbon and re-immerses briefly in the etch solution without current.

In automatic and semi-automatic plants an alkaline electroclean is introduced following such an acid electro-etch harnessing the hydrogen scrubbing effect to brush away any loose carbon that forms.

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 recommended; 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 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: soak clean, cathodic or ultrasonic clean, rinse, hydrochloric acid dip, rinse followed by a flash of copper from a cyanide or alkaline cyanide free solution. A somewhat more elaborate sequence may be followed with engineering applications when manually preparing components such as complex machined castings and the like. For example, the work may be scrubbed with pumice after cathodic cleaning, and the formulation of the acid dip may be varied.

The sequence for beryllium copper is specialised. Several methods have been used. A suggested sequence is; soak clean in a suitably formulated alkaline degreaser, rinse, pickle in an ambient sulphuric-peroxide mixture, electro-strike in a basic copper sulfate solution containing no additive or brighteners, and then proceed to the next plating step. The reason for employing an acid strike is because beryllium forms insoluble salts with the cyanide copper strike most commonly used.

ZINC-BASE MATERIALS

The alloy used in zinc-based die castings contains about 4% aluminium and very small amounts of magnesium and copper. The castings are often plated with decorative coatings of nickel plus chromium or other decorative top coats, 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. Fortunately, the material straight from the mould is generally very clean and does not require aggressive cleaning. This is why it is extremely important that die-castings are not allowed to stand around oxidising in the workshop environment. Usually the castings are immersed in an purpose-formulated mild alkaline soak cleaner and subse-

quently anodically or ultrasonically 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, usually an ambient 2% sulphuric followed by thorough rinsing.

A copper coating about 10µm thick is then applied before nickel, brass or chromium plating. The copper may be deposited in one layer from a cyanide solution, but sometimes only 3-5µm is applied from the 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 pre-treatment 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 chemically displaced from the solution. This in turn deposits on the aluminium. As this initial coating may be thick and highly porous, it is common practice to totally dissolve it in nitric acid solution, removing it, and then repeating 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 any coating of choice.

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, produces a coating that can be plated directly 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 in a specialised alkaline cleaner; 2) cathodic clean again in appropriately formulated cleaner; 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 breakthrough occurred in the early 1960's when it was found that truly adherent deposits could be applied to a particular grade of ABS (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 of chemical links to be established. Polypropylene has been used but presents more difficulties than ABS and as a result its use has remained very limited.

Following on degreasing and etching, the work is thoroughly rinsed before being subjected to an activation process. 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. Subsequent processing depends on the application; a possible sequence would be: bright, levelling acid or pyrophosphate copper

(starting at low current density, as explained earlier), bright nickel with a choice following up in brass, gold, or chrome.

SPECIFYING & 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. it's initial surface condition
3. it's 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. intermediate coatings or finishing processes that are to be specifically avoided e.g. nickel underlays on jewellery or hexavalent chromate conversion coatings on zinc plated components
7. the thickness(es) of coating to be applied (usually in terms of minimum, or sometimes average, thickness; an upper limit may occasionally be imposed);
8. any pre or post-plating treatments necessary, in particular, to avoid hydrogen embrittlement;
9. the appearance demanded and an indication of the positions where contact marks will be acceptable;
10. batch size and frequency
11. containers to be used for transport
12. inspection procedures
13. performance testing required

It is best if the information required in items 1 - 8 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 9, as the judgement of appearance is manifestly subjective. An accurate estimate, under 10, 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 12 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 13 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.

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 in respect of damages and losses that occur on the platers premises.

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 rough breakdown of a typical electroplating company's costs:

Wages, Salaries & on-costs	30 - 40%
Energy	15 - 20%
Balance of costs: Rentals, Depreciation, Insurance, etc	15 - 20%
Plating Materials	20 - 30%
Transport	5 - 10%

Clearly, excepting the case of precious metal plating, the raw materials consumed contribute a comparatively low percentage of the overall input costs on a plated item; plant upkeep, 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. 