Electroforming

What is electroforming?

Stated briefly it is a method of manufacturing metallic objects where metal is deposited from a solution, usually aqueous, of soluble salts of the metal in question using technology similar to that employed for producing electrodeposited coating, that is electroplating.

Nickel is the most widely material used in electroforming followed by copper and then precious metals such as silver and gold. Therefore this summary focusses on nickel electroforming

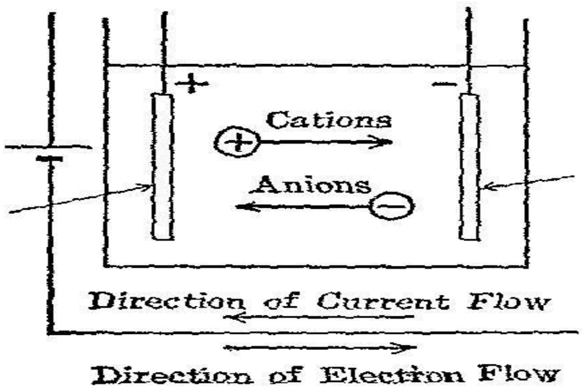
It is perhaps, in one respect, amazing that this process should remain almost unrecognised, even by highly qualified technologists and engineers. It is perhaps even more surprising since nickel electroforming is the only method by which the vital properties of most of the products for which it is employed can be achieved.

This is probably due however to the fact that almost all of the products made by electroforming are intermediates in the manufacture of other products which give no indication as to the route by which they were made.

Process technology summary

In order to appreciate the nature of nickel electroforming it is not necessary to know all of the intricate details of the processes used. However, it is useful to look briefly at key technical aspects of the process if the ensuing descriptions of the applications are to be understood.

Basically nickel electroforming technology plating has not changed since the 1840s. An anode and cathode are suspended in an aqueous solution of a nickel salt and a direct current is passed between them causing nickel metal to deposit on the cathode. The principles of the equipment used are shown below, together with an illustration of a typical process plant.



The most significant development in electrolytic nickel deposition processes appeared in 1916 when Oliver Watts published his work defining the composition of a solution based on nickel sulphate with additions of nickel chloride and boric acid. The 'Watts Solution', as it became universally known, has remained the mainstay of the nickel electroplating industry for the last 95 years.

The most important development of the standard Watts formulation appeared in the 1950s with the introduction of nickel sulphamate – $Ni\ (HSO_3.NH_2)_2$ – as a replacement for nickel sulphate – $NiSO_4$ – as the main bath constituent. Nickel sulphamate solutions have an inherently higher electrical conductivity than sulphate-based ones that allows higher rates of deposition to be employed which is a significant economic advantage.

Differences between electroplating and electroforming

Electroplating is a process for coating the surface of a substrate material, most usually metallic but also certain type of plastics.

Electroforming, on the other hand, is a process for manufacturing metallic articles that have an existence independent of the substrate onto which they are deposited.

Three basic differences arise as a result.

1) Coating thickness

An electroplated coating only needs to be thick enough to provide the properties for which it is deposited. This is most frequently improved corrosion resistance to a substrate such as steel or brass. Typically thicknesses between 3 and 40 μm are employed.

Similar deposits used for electroforming, however, need to be thick enough to have mechanical properties that allow the form to have an independent existence. The thinnest commercially available electroformed material is pure nickel foil at 9 μm. The forming process can however be continued to produce deposits up to 5 mm.

2) Deposit adhesion.

A great deal of care is taken in the electroplating process to ensure that the adhesion between the deposit and substrate is as perfect as possible.

With electroforming, however, it is essential that the electrodeposit can be separated from the substrate onto which it is deposited.

3) Deposit stress

With electroplating systems a degree of internal stress in the deposit can be tolerated as along as the adhesion between it and the substrate is good.

Since the adhesion in the electroforming process must be as low as possible the substrate cannot exercise restraint to overcome internal stress in the deposit. Consequently electroforming processes must, in general be ones that do not create either tensile or compressive stress in the deposit.

This is the prime reason for the preference for nickel sulphamate over nickel sulphate in electroforming processes.

Major applications of nickel electroforming

CD, DVD and BR Manufacture

The ability to record and reproduce sound is taken for granted by 21st century society but it is worth remembering that the enabling technology for sound recording did not exist 120 years ago.

The basic principle of the manufacturing process using the flat discs has remained unchanged in principle over this long period. The original information is imprinted, as a three dimensional image, into a relatively soft organic film supported on a rigid substrate.

However, organic film onto which the original information is imprinted – be it by mechanical means or laser technology - is extremely soft and totally unsuitable for further replication operations.

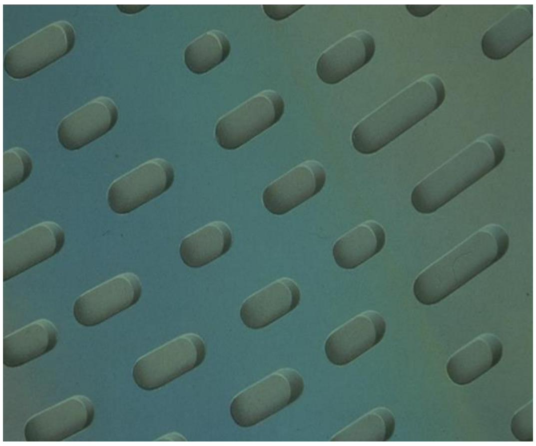
So in order to reproduce audio records, CDs, DVDs or BDs cheaply and in large quantities it is necessary to manufacture a completely precise replica of the original information in a hard, wear resistant material that can be used as a mold to manufacture the final product by a relatively inexpensive mass production technique.

In the case of earlier audio discs a groove was cut into in a thin lacquer film by a precision mechanical process.

Major improvements in this basic technology were effected in a number of steps during the 20th century ultimately resulting in a stereophonic sound capability and a capacity of 20 minutes per side on a disc 300 mm in diameter, played at 33 rpm.

A fundamental change, however, occurred however during the 1980s when compact discs were developed. With CDs the original information is produced onto the soft organic film by computer controlled laser technology rather than mechanical methods. The process therefore is digital and fundamentally more accurate than the analogue method. Consequently the capacity of compact discs is much greater than that of discs produced by analogue methods.

The illustration shows the surface of compact disc produced in the late 1980s and demonstrates the surface depressions that carry the digital information.



At this stage of the development of the discs the depressions would typically be 0.2 µm deep by 0.4 µm wide by 1.6 µm long. The information is carried by variation in the depression length. A disc would typically have 30,000,000,000 depressions on its surface all of which must be the correct length, depth and width and in exactly the right position on the disc surface.

The electroforming process has been refined to a remarkable degree that enabled the development of video discs (DVD) and ‘Blu-ray’ (BD) discs.

Production numbers

Polycarbonate discs are injection moulded from a 290 µm thick nickel electroformed mould to a finished thickness of 1.2 mm. During 2010 the collective disc output in the European Union for all three type of disc was 4,300,000,000.

Manufacture of Holograms

The technology for producing holographic images was invented in 1947 by Hungarian-British physicist Dennis Gabor. He was awarded the Nobel Prize for Physics in 1971.

Holographic originations suffer from the same disadvantage as those used for disc production in that they are created in an organic, photosensitive mechanically soft and fragile film. Fortunately, however, these originations also consist of very shallow three dimensional images. Consequently hard copies of the soft origination surface can electroformed in nickel using similar techniques to those used for optical discs.

The process route for hologram production is almost identical to that used for optical disc and CD manufacture. The surface of the origination is coated with a very thin layer of silver metal to make it electrically conductive. Nickel metal is then electrodeposited onto this silver layer to produce a mechanically robust copy, perfect in detail, of the original image.

An excellent example of the precision achieved is provided by a security feature on the holographic image of a butterfly, shown alongside. On one of the wings of the butterfly is a circle 0.5mm diameter.

Within that small circle there is a map Europe as shown giving the precise location of the capital cities of each of the countries included.

Nickel electroforming of Screen Printing Cylinders

Screen printing is a technique that has been used for over a thousand years to transfer decorative images to substrates, such as fabrics. In order to process, in an economic manner, the huge volumes of patterned materials required by modern society, it has been necessary to invent a, innovative novel and dedicated process.

The technology involves transferring the inks of different colours that make up the decorative patterns to the substrate materials through perforated metallic rotating cylinders as shown alongside

A typical cylinder consists of a long, thin-walled tube, typically 400mm in diameter and up to 4 metres in length. The cylinder wall thickness is only about 0.1mm and it vital that this is very accurately controlled and consistent over their whole length and diameter. A typical example is shown in below.

In order to produce the required printing patterns, cylinders are manufactured with billions of tiny holes in their walls, ranging in size from 0.6 mm. down to 0.08 mm. in diameter.

Electroforming in nickel has proved to be the only method by which the cylinders can be manufactured to achieve this exacting level of precision

Manufacture of screen printing cylinders has grown to become by far the largest single application of nickel electroforming in the world. An estimated 1,500 tonnes of metal a year are used for this application in Europe alone.

The perforated cylinders enable over 10,000,000,000 m^2 of useful and aesthetically pleasing products, principally fabrics, wallpaper and carpets to be printed each year

Precision Engineering

Grinding technology

Although grinding has been a widely used metal working technique for thousands of years precision levels have now risen to the extent that grinding to an accuracy of 0.005 μm is required. If this is to be achieved, then the grinding devices used must be manufactured to a similar level of accuracy.

To maintain this accuracy the profile of the grinding device must be 'dressed' at regular intervals.

Because grinding wheels are made from extremely hard materials, the device used to maintain the profile of the wheel must be even harder. The devices are known as rotary diamond dressers.

Nickel electroforming is the only process by which the phenomenal accuracy essential with the most accurate and complex dressers can be achieved. Diamonds, which act as the grinding medium, are attached to the inside of a hollow cylindrical graphite mould which this is a three dimensional reverse image of the required dresser. The diamonds are secured in place by electro -deposition of nickel onto the inside of the mould the thickness of which is increased sufficient a free-standing electroform that is capable of surviving the rigours of the grinding process.

Surface Finish Standards

One of the many requirements of high precision engineering is to be able to quantify the surface finish of a machined part accurately and reproducibly. Primary surface standards are extremely expensive to manufacture, and in view of the accuracy required on their operating surfaces.

Electroforming in nickel has been found to be the only method by which secondary standards can be made with the same degree of surface precision as the primary standard, at a lesser price. These standards are essential to achieve the high standards of surface precision required by modern engineering industry

Thin nickel products

The manufacture of thin products is an application almost tailor-made for nickel electroforming, since it fully encompasses the advantages of both the process and the material.

Electroforming works in the opposite direction to conventional metallurgical forming techniques. Thin products, including plain foil, perforated foil and foam are deposited gradually from the first layer of atoms formed on the substrate surface until the required thickness is reached.

Plain Nickel Foil

This is manufactured by continuous electroforming onto a cylindrical rotating mandrel which allows foil thickness to be very accurately controlled, between 9µm and 100µm. Since the forming process is continuous the product can be produced in lengths up to 1,250 metres.

Chemical and metallurgical properties of 99.95% pure nickel electroformed foils are comparable to those of foil products produced by conventional thermos/mechanical processes.

Electroformed perforated nickel foil

Thin nickel foil products such as screen printing cylinders (see above) are regularly manufactured with hole patterns in situ. This is done by depositing a non-conducting layer onto the surface of the substrate onto which nickel is to be deposited.

The required deposit pattern is developed in this layer by exposing it to visible light or UV radiation, through an appropriately patterned mask. Selected areas of the resist are shielded from the radiation by the mask and remain unaffected. Electroforming technology thereby enables perforated thin foils to be manufactured with a variety of hole geometry of carefully controlled size, shape and position.

There is an extremely wide range of applications for perforated nickel foil products, including sieves, inkjet nozzle plates, spray nozzle plates, electronic lead frames and foils for electric razors.