Electroforming is for Everyone

By Ron Parkinson

We all have some contact with electroforming every day without realizing it, and yet very few people are aware of how it has affected our daily routines and lifestyles. It brings us color and beauty ... it provides us with high-quality sound and visual entertainment ... it is the only economical way of producing many of the items we see and touch and use every day. We have become dependent on it, and don't even know it.

Electroforming requires a versatile metal, and most often nickel is the preferred choice. This article will take us through a typical day and describe some of the ways in which electroforming enters our lives.

The Process . . .

Electroforming is a unique metal fabrication process. It is extremely versatile and serves many different industries. The rocket thrust chambers used on every shuttle launch, for example, are made by electroforming. Huge rotary printing screens—up to six meters long—are electroformed, and the process is irreplaceable in the manufacture of optical read-out discs that we take so much for granted. It is used to produce some micro-medical equipment, such as a microturbine/ cutting tool small enough to pass through diseased arteries to remove accumulated plaque. It has also played a huge role in the ongoing reduction in the size of computers.

Electroforming is defined in ASTM B-431 as "the production or reproduction of articles by electrodeposition upon a mandrel or mold that is subsequently separated from the deposit." Basically, therefore, it is a simple process that has become indispensable because it is capable of producing parts that cannot be economically produced in any other way. It can be used to produce large and small parts; to reproduce the finest surface detail and texture and the methods used for mandrel production, preparation, electrodeposition and part separation have reached a high level of technology. The largest use of electroforming is in the production of a wide range of screen products and molds, where the precise reproduction of perforated patterns, surface contour and texture are very important requirements. Nickel is used in the greatest number of electroforming applications, and with good reason. It can be deposited at high speeds, if necessary, and reliable, easily controlled electrolytes are available. In addition, physical properties of the deposit can be controlled over a wide range.

Perhaps none of this is news to those closely associated with electroforming. In fact, we are familiar with some very specialized applications that are exceptional in scale, technology and expertise. These would include the use of electroforms in the aerospace, aircraft and electronic industries, for instance, where mechanical and physical properties are usually critical. There are many other applications, however, to which we can more easily relate, because we have experience with them every day. Is the public aware of its dependence

Fig. 1—A selection of very long rotary printing screens.

on electroforming for many of these items we accept so easily? I would suggest the answer is no. More importantly, are designers and engineers aware of the full capabilities of the process? Once again, in most cases the answer would be no.

Let's consider, therefore, a typical working day in the life of an average couple (we'll call them Pat and Bill—it will become very obvious that electroforming is indeed for everyone.

At Home ...

The day begins as it does in most households, with a stretch and a yawn and the immediate prospects of a shower, a shave and a coffee "fix." While Pat places first claim on the shower, Bill makes coffee, with no thought to their first exposure of the day to electroforming.

The permanent coffee filter, for example, is made of electroformed nickel segments produced on a flat nickel-plated steel mandrel, coated with a photoresist pattern that enables several hundred segments to be produced on each cycle. Thickness is about 130 μm, and deposition time is between one and two hr. The segments have precise, perfectly reproducible dimensions, and may receive a flash of gold before being molded into their conical plastic frame. Anyone for sugar? One of the oldest applications for electroformed nickel screens is for centrifugal filtration in sugar production.

Meanwhile, back in the bathroom, the plastic tub has been put to use without any thought of how those anti-slip patterns were produced in the surface. Well, the tub was produced on an electroformed nickel mold that, in turn, was deposited on a mandrel with a very smooth surface finish ... except for the textured surface of the anti-slip pattern. Whatever the surface texture, it is reproduced perfectly in reverse in the electroform.

Then, if chins or shins must be shaved for the day, the perforated foils in the electric razor are also made from electroformed nickel, deposited on large stainless steel mandrels that may produce up to a thousand foils per cycle. Thickness is typically 50 μm, deposited in about 30 min, and the foils are removed from the mandrel in one sheet so that individual foils can be separated in much the same way as postage stamps.

Time to dress. Casting her eyes over the options hanging in her closet, Pat passes over the plain suit and the simple black dress and, to the joy of nickel suppliers and electroformers everywhere, selects a bright, multi-colored patterned outfit that brightens her day ... and our industry. You see, rotary printing screens are used to produce these patterns, and the screens are made by electroforming with nickel. The more colors, tones and patterns on the fabric, the more screens are required to print it. Each color or tone requires a different screen, so for printing multi-colored patterns, up to 10 screens could be needed. Over the last several years, fashion designers created a huge demand for screens, most of which are used for textile printing, with still more used for carpets and wallpaper.

Electroforming textile screens is done on a very large scale, but with great precision. Screens may be several meters long, and are typically 20 cm in diameter. The mesh size normally would be in the range of 100–200 and screen thickness about 100 μm. Inspection requirements are very thorough, in spite of screen size, and quality standards are extremely high. Most screens are made in Watts-type electrolytes, containing additives that produce a low compressive stress in the nickel. The hole pattern on the cylindrical mandrels has traditionally been made by an etch-and-fill process on a copper surface, but etching has now been replaced, for the most part, by a mechanical indenting method. A thin flash of chromium or nickel may be used over the exposed copper to increase life and help in release of the electroform. Such mandrels should have a life of at least 200 cycles.

The production of rotary printing screens for textile, wallpaper and carpets remains the largest, single application for nickel electroforming.

At Work ...

The day has just begun, and already the importance of electroforming has made its mark. This morning, Bill is flying out of town to make a brief business call, and Pat is driving to the office. It's a comfortable, well-appointed family car, and the leather in the door panels gives it a luxurious look and feel. Well ... not *really* leather, but the appearance and texture give that impression. It's actually a vinyl skin produced on a contoured mold by slush-casting, and the mold is produced by—what else?—electroforming.

For the molds, a model of the door panel was probably made in wood, then covered with a piece of high-quality leather. A casting of the part would then be made, probably in reinforced plastic, and then a copy of the original model would be produced in plastic from the casting. This then becomes the mandrel for electroforming. It would be metallized with silver and nickel deposited on the conductive surface to a thickness of 2–3 mm over a period of five or six days. The surface condition of the leather is perfectly reproduced. Such methods

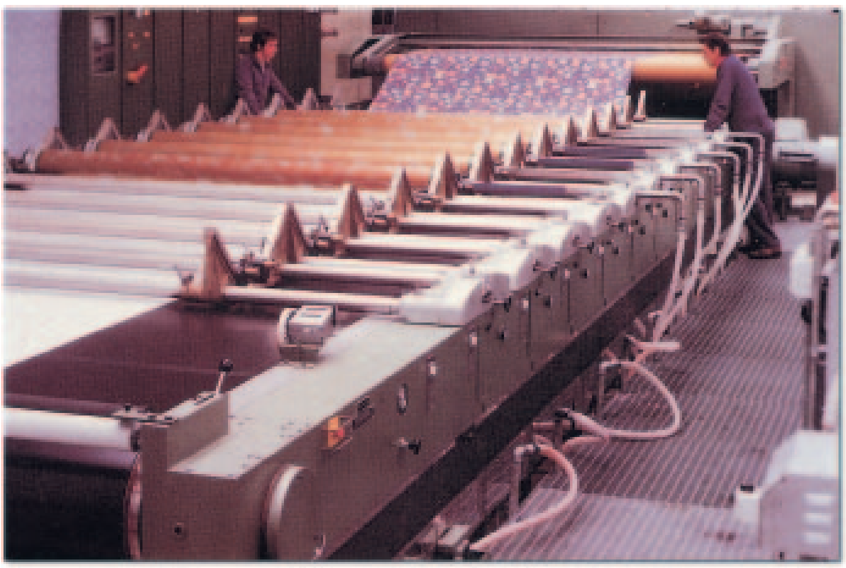


Fig. 2—Textile printing machine. Fabric is passing beneath seven screens to produce the finished pattern.

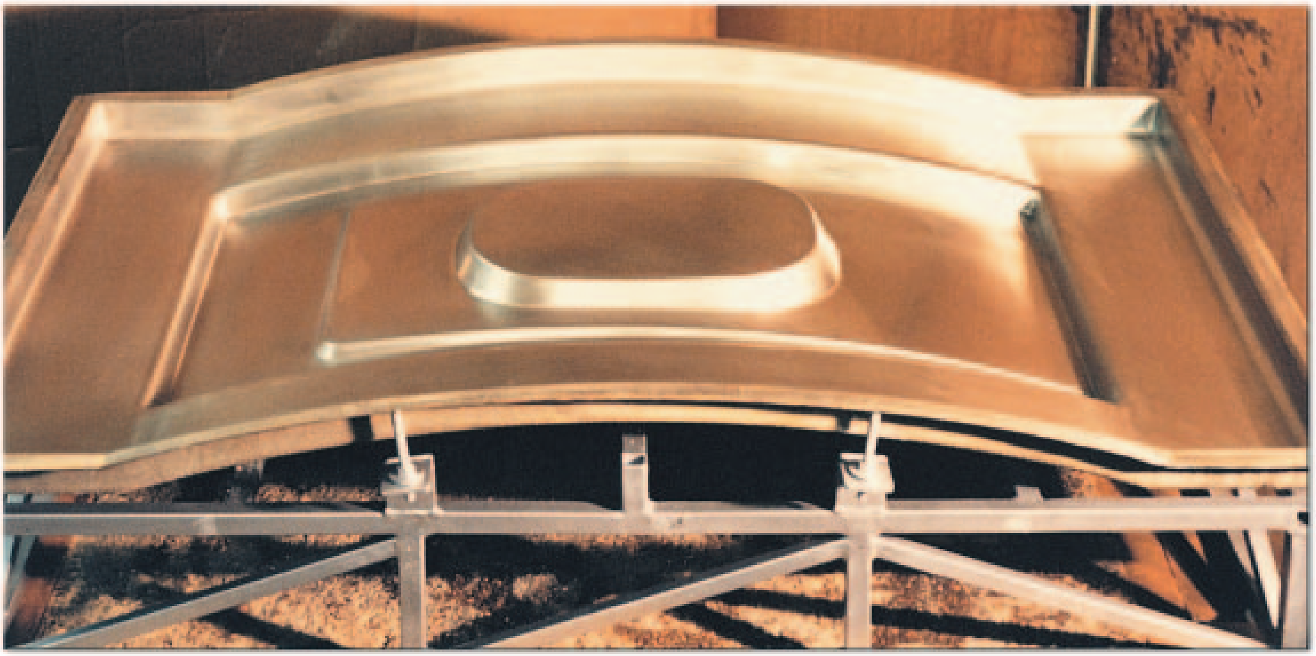


Fig. 3—Nickel mold for producing textured vinyl skin for Airbus window panels.

are used for electroforming molds for other automotive components that have a textured surface, such as vinyl skins for dashboards.

Other industries, such as the aircraft industry, also depend on nickel electroforming to produce molds that will provide the required surface condition on a variety of plastic parts. In fact, Bill has a window seat on his flight today, and the vinyl skins on the window panels were also produced on electroformed nickel molds. When coming in contact with textured, contoured surfaces on vinyl parts, it's difficult not to think of electroforming.

At Pat's office, there is a load of photocopying to be done before lunch. Fortunately, there is a large, high-speed copier available that produces high-quality copies. And why not? One of the major components—the photoreceptor—is made by electroforming. This model uses a flexible, nickel photoreceptor belt, about 50 cm diameter and 45 cm wide. It is about 125 µm thick and is deposited from a sulphamate electrolyte at very high current density in less than 30 min. The cylindrical mandrels are chromium-plated aluminum, which is an unusual application because it is the outer surface of the deposit—not the inner surface in contact with the mandrel—that is the functional surface in the copying machine. Consequently, not only is the surface of the mandrel extremely important, but very high quality must also be maintained at the full deposit thickness. Testament to the success of this application is the fact that 600,000 belts were produced every year over a 20-yr period.

Because tonight Bill will be taking Pat out to dinner for her birthday, she decides to skip lunch and take a walk outside instead. Electroforming plays a big role in how much Pat enjoys her walk: Numerous rubber heels and soles for shoes have been produced on electroformed molds to provide lunchtime walkers with comfortable footing. On her way back, Pat stops at a popsicle stand for a cool treat in her favorite flavor, not once thinking about how they are made in such large quantities. Well, the self-contained, automatic equipment is very efficient in filling molds, inserting sticks, quick-freezing solution and removing the finished product. It's so quick and easy that electroformed nickel molds with various shapes are frequently used in great numbers in this equipment. Typically, the nickel would be deposited to a thickness of up to one mm on stainless steel mandrels at current densities of 10Å/dm^2, using nickel sulphamate electrolyte. Molds for other confectionaries, such as chocolates, are often made by a similar process.

The dollar bill exchanged for the popsicle seems well spent on such a warm day, but is Pat thinking yet of electroforming? Not at all. In fact, like most people, she is unaware of the intricate design and detail on all the paper currency handled in such enormous quantities each day. In most countries, the original designs are usually produced on steel plates by master engravers and then, following a series of hardening and reproduction stages, the final plates or rolls for use on the presses are electroformed in nickel sulphamate solutions. Every detail in the original

Fig. 4—Huge nickel mold for producing hardboard with simulated wood grain.

Fig. 5—Electroformed 24K gold jewelry produced on wax mandrels.

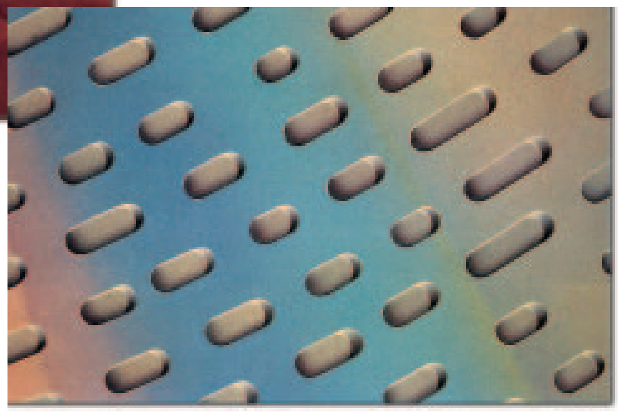


Fig. 6—Submicron pits in a CD surface, perfectly replicated by electroforming.

engraving is reproduced in the final nickel electroform, ready for transfer onto those new, crisp bills that pass quickly through our fingers. The U.S. Bureau of Engraving and Printing electroforms 4,000 plates per year and prints six billion bank notes.

While waiting for his return flight, Bill looks for an appropriate birthday card for Pat at the airport gift shop. He's amazed at the overwhelming selection of greeting cards—pictures and messages, romantic and funny, plain and sculptured. The important thing to remember is that the sculptured patterns were probably produced by embossing with an electroformed nickel die, so we hope Bill chooses one of those!

Later, Pat picks Bill up at the airport and, when they finally pull into their driveway, they sit back and admire the appearance of the house they have lived in for so long. It is inviting and warm-looking, with cedar siding that has required very little maintenance and seems unchanged after 20 years. That's actually not too surprising, because it isn't natural cedar. Although it is a real wood product, it was made by processing wood fibers to expand them prior to compression at elevated temperatures under high pressure, producing hardboard, which can be up to 50-percent denser than natural wood. Of course, during the pressing the surface takes on the appearance of the platen surface, so, if suitably textured molds are attached to the platens, a whole range of wood grain can be reproduced. The molds used are ... you guessed it ... electroformed nickel, and their size could be up to 5 meters x 2 meters. The original wood-grain pattern would typically be reproduced by reinforced plastic lay-up on selected wood prior to electroforming.

Thickness of the nickel could be up to 12 mm and, because low current densities are used, deposition time could be up to two weeks. With such large electroforms, therefore, very low stress in the nickel is necessary, because any premature lifting of the deposit from the mandrel as a result of internal stress results in much-wasted time and nickel. A single mold could weigh up to 1 MT. The scale of the electroforming operation and the wood surface replication are impressive.

At Play ...

For her birthday dinner, Pat is wearing the jewelry Bill has just given her. Both the necklace and intricate bracelet in 24K gold are originals, costing much less than you might expect. Because they are hollow, they are quite lightweight and comparatively inexpensive. They were produced by electroforming on wax mandrels that were subsequently melted out. Design capabilities are limited only by the imagination.

At the end of a delicious dinner, Bill pays with a credit card, complete with its embossed security hologram—another outstanding example of high-tech electroforming.

This development is a very demanding application for electroforming because of the precision and detail required. The three-dimensional holographic imaging on the credit card was produced by embossing aluminized plastic film with an electroformed nickel stamper. Production of the stamper has involved computerized three-dimensional imaging of the subject, followed by transfer onto a photoresist film on an optically flat glass plate by laser imaging. This pattern, which must be reproduced perfectly throughout several electroforming stages, consists of a series of very fine lines, varying in width and depth with both dimensions less than one micron. Nickel masters are produced at a thickness of about 0.5 mm from the image on the photoresist, and then, by a series of reverse electroforming stages starting with the masters, the final nickel stampers or embossing tools are deposited. Hologram production costs have now become commercially attractive, and the expertise of the electroformer has contributed greatly to the emergence of holography into everyday use.

Back at home, Pat and Bill decide to listen to a little music before ending the evening. Tapes, LPs (long-playing records) or CDs ... which will it be tonight? Either LPs or CDs would be a good choice, because both include nickel electroforming as a key operation in their production. Stampers for molding records have been produced by electroforming since about 1930, but the development of compact discs required tremendous refinements to be made in the process to obtain the exceptional sound quality of CDs. Improvements have been so successful that plants producing more than 100 million CDs per year are not uncommon. The industry depends on the perfect replication of surface detail by electroforming.

The basic processes for LP and CD stamper production are similar, and surface replication closely corresponds to that used for hologram molds (*i.e.*, final stampers are made following "mother" and master electroforming stages). The need for refining the process for CDs is obvious when the surfaces of LPs and CDs are compared. An LP surface has a continuous spiral groove, typically 25 µm deep and 25 µm wide, with a spacing between the pits. There are typically 30 billion of these pits on a CD surface. Refinements for CD stamper production include clean room conditions, sealed electroforming tanks, submicron filtration units and fully computerized operation. Greater control of nickel deposit properties such as stress and thickness is essential. Thickness, for instance, is controlled at 300 ±5 µm, whereas in LP production, thickness variations may be as high as 25–50 µm.

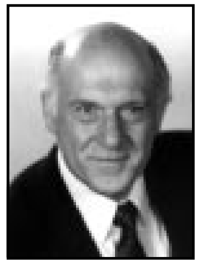
In addition, the starting surfaces for the two types of records are very different. For LPs, the original sound is transcribed onto a nitrocellulose lacquer film on an aluminum disc. For CDs it is transcribed by laser onto a photoresist film on a polished, optically flat glass disc. For both, it is then necessary to replicate these surfaces through three electroforming stages to produce the stamper that molds the final plastic disc with the excellent sound quality that we experience today. Approximately 80,000 CDs can be injection-molded in polycarbonate from each stamper, compared to only 2,000 vinyl LPs by compression molding.

CD molds and hologram-embossing tools production are outstanding examples of electroforming as defined by ASTM. Electroforming is a unique, versatile process with an enormous number of applications—many in the field of high technology. It has contributed greatly to the day that our typical couple just experienced. And, whether they know it or not, Pat and Bill owe a debt of gratitude to electroformers everywhere. P&SF

Acknowledgment

The author wishes to thank the Nickel Development Institute (NiDI) for its support in the preparation of this article. Additional information on electroforming and all other applications for nickel is available from NiDI at 416/591-7999.

About the Author



Parkinson

Born and educated in England, Ron Parkinson emigrated to Canada in 1954. He worked for eight years as a materials and process engineer in the aircraft industry before joining the R&D department of Falconbridge Ltd., in 1963. He became manager of product development with responsibilities in all areas of nickel applications, with emphasis on electrolytic processes. In 1982, he transferred to the marketing department and later became director of market development, with worldwide responsibilities. He retired in 1991 and currently does some consulting work with the Nickel Development Institute (NiDI) in Toronto. In this capacity, he recently prepared an electroforming course that has been successfully presented jointly by NiDI and AESF in 1996 and 1997. He is a member of the Toronto Branch of AESF.