Gold Electroplated Spectacle Frames

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Electrocoating of spectacle frames is one of the more traditional uses of gold and its alloys and may tend to be regarded as a simple and straightforward process. In this review, the authors show that, in fact, careful control and monitoring of manufacturing conditions and quality are essential to obtain a satisfactory product.

Spectacle frames are expected to give many years of service during which their functional and aesthetic qualities should remain unimpaired by the corrosive and abrasive conditions to which they are exposed. Coatings of precious metals and especially of corrosion and wear resistant gold alloys are well suited to meet these demands and have indeed found wide application in the finishing of spectacle frames.

Originally, frames were manufactured from substrate material onto which a protective layer of gold alloy had been mechanically clad before profiling (rolled gold). Currently, most spectacle frames are electroplated with gold or gold alloys. Both products have advantages and disadvantages.

Rolled gold coatings are generally superior to electrodeposited coatings in respect of ductility, adhesion and the range of colours in which they are available. However, cut edges, machined areas and welded or brazed joints on products made from rolled gold are not protected unless a final 'cosmetic' electroplate is applied. Furthermore, great care has to be exercised in order not to damage the gold layer during fabrication and more particularly final polishing (Figure 1). Also, as a result of the profiling process, substantial thickness inhomogeneities may occur, with heavily deformed areas having comparatively thinner gold coatings. Thus, parts with a sharp curvature, which often have to endure large strains during forming, are also those where the gold thickness is diminished.

On electroplated products the highest coating thicknesses are usually found on edges, projections, convexities, etc., where they are most required. Hence, electroplating is particularly well suited for the coating of intricate designs. The process is normally carried out after fabrication, once all forming, shaping and joining operations have been completed

and risks of damaging the coating during manufacture are eliminated. All visible parts of the frame are uniformly finished and protected and, if fashion suddenly dictates a change in colour, this can easily be met by electroplating prefabricated frames held in stock. The main disadvantages of electrodeposited layers are their limited ductility and the restricted choice of colours in which they are available.

Requirements for Substrate and Coating Materials

Two main requirements for a good spectacle frame substrate metal are springiness and ease of bonding. The bridge, temples and lens frames also call for a material with good impact strength. In addition, the substrate alloy itself should have good corrosion resistance since it will be exposed if the protective gold layer is damaged or worn through. For these reasons, copper-nickel based alloys are mostly used. Typical materials are German silver, Monel, brass and tin bronze.

Fig. 1 Cross section through a lens frame made of rolled gold. Careless polishing led to local wear through the protective gold layer

Fig. 2 Fully automated electroplating line for the deposition of pure and alloyed gold coatings onto assembled spectacle frames. The line is also used for the deposition of flash coatings of rhodium onto white rolled gold or electroplated frames. On a 1 shift/day basis, the capacity of this unit is 10^6 frames/year

Photograph by courtesy of Ferdinand Menrad Brillenfabrik, Schwäbisch Gmünd, West Germany

The coating on spectacle frames is expected to withstand mechanical wear from constant rubbing by skin and hair and from cleaning. This requirement alone virtually precludes the use of fine gold coatings. Gold alloys with their higher hardness and resistance to scratching and wear are preferred. On the other hand, the coatings should be ductile and adherent enough to avoid cracking or spalling during initial adjustments of the frame to the customer's requirements, during accidental bending or impact.

Gold alloys which are already preferred for functional reasons also fulfill colour requirements for spectacle frames. By codeposition of gold and various elements such as silver, copper, cadmium, palladium, nickel, cobalt or zinc, coatings ranging in colour from red to yellow to white can be produced. Provided the gold content of these deposits is sufficient, outstanding corrosion and tarnish resistance to natural and artificial chemical substances is achieved.

Irrespective of the type of coating selected, the plating procedure, equipment and electrolyte used should be reliable so as to ensure reproducible functional properties and colour of the deposit. Above all, the coating must be free from pores if it is to protect the substrate effectively against corrosion.

Electroplating of Spectacle Frames

Gold plating is normally carried out on fully assembled frames placed onto specially designed racks (Figure 2). The pretreatment is of the usual type for rack-plating.

Very often, intermediate nickel or copper layers are deposited in order to mask small surface defects on the substrate and reduce final polishing costs. These

layers can, however, greatly affect the corrosion resistance of the coated parts and the adhesion of the gold alloy deposit.

Gold alloys can, in principle, be deposited from the following electrolytes:

- (1) Alkaline-cyanide electrolytes (pH 8.5 to 13)
- (2) Neutral-cyanide electrolytes (pH 6 to 8.5)
- (3) Acid-cyanide electrolytes (pH 3 to 6)
- (4) Sulfite electrolytes (pH 6 to 11).

The electrolyte most widely used for the deposition of 18 carat gold alloys is of the alkaline-cyanide type and produces gold-copper-cadmium coatings. By varying the bath composition and operating parameters, the colour of the deposits in terms of DIN 8238 can be changed from 1 N to 4 N. However, one important limitation arises from the fact that the corrosion resistance of these deposits depends upon the degree of solid solution formation between gold, copper and cadmium. Alloy electrodeposits which do not form solid solutions usually show lower corrosion resistance. Deposits from acid-cyanide electrolytes contain in general iron, cobalt or nickel as alloying elements. These deposits (99 per cent gold) are hard and wear resistant but show little ductility. In recent years, gold alloys deposited from sulfite electrolytes have generated interest and, using them, gold-copper-palladium deposits with colours approaching those of rolled gold and white gold-cadmium and gold-zinc deposits have been developed.

In order to achieve the exact colours wanted the finished frames may be given a last flash coating. In most instances this is of 'coloured gold' (*Farbgold*), though with white gold frames it may be rhodium or, more recently, ruthenium.

A common practice is to keep the caratage of the gold alloy deposits as low as possible for cost reasons. On the other hand, it must be borne in mind that alloys of caratage lower than 18 exhibit increased susceptibility to tarnishing and corrosion. Therefore, composite coatings of low and high caratage alloys, the latter on top, are sometimes used.

The thickness of the gold deposits may vary over a wide range, depending on quality and price considerations. The lowest values used are about 2 μm and the highest are close to 15 μm .

Testing of Gold Alloy Electrodeposits

In view of the stringent requirements that have to be met by spectacle frames electroplated with gold, detailed testing procedures have been established to control their quality. In some of these, the physical properties of the deposits are measured while in others the performance of the frames in service is evaluated by accelerated means.

Deposit Thickness

The coating thickness distribution on a profile is normally measured microscopically on a cross section, after the surface has been protected by a thick electrodeposit of copper or nickel for metallographic preparation. Depending upon the surface profile it may also be possible to measure the thickness non-destructively by β -ray backscatter techniques if standards with identical base material and gold alloy composition are available.

Deposit Hardness and Wear Resistance

Microhardness of electrodeposits is usually determined on the surface or on a polished microsection. The thickness of the deposits should be 10 μm or more in order to obtain reliable values by such determinations.

There is no generally accepted wear testing method for spectacle frames since it is very difficult to simulate the real service conditions in an accelerated wear test. A widely used procedure, however, is to determine the number of times a loaded test piece must be rubbed against a certain length of cloth, with or without addition of fine alumina powder, in order to wear the coating through. This test at least makes comparative assessments possible. It should always be kept in mind that high hardness does not necessarily mean high wear resistance. In fact, hardness should be limited since very hard deposits tend to crack. Furthermore, under certain conditions, high hardness results in low wear-resistance because the deposit cracks away in small flakes due to its brittleness. Also, deposits on parts such as temples must be able to withstand bending. These considerations make it necessary to compromise in regard to the optimum hardness of gold alloy deposits on spectacle frames.

Deposit Adhesion

Adhesion tests for gold coatings are the same as those used for electrodeposits of other metals or alloys (American Electroplaters' Society, Research Project No. 3; ISO 2819/I). The methods used for spectacle frames are either a file test at a corner or a bending test, preferably of the temples, over a mandrel which may be typically 30 mm in diameter with an angle of 30 degrees. The development of cracks in the protective coating is permissible provided that no flaking off occurs.

Deposit Ductility

The mandrel adhesion testing method mentioned above can also be used for the assessment of deposit ductility. Its conditions are so severe that it will produce fine cracks in most deposits. At the higher thicknesses, gold-rich deposits from sulfite electrolytes seem to be the most ductile. Cracks are sometimes difficult to detect macroscopically but show up on a microsection. Gold alloy coatings on bright nickel are much more prone to cracking than those deposited on a softer base.

Deposit Composition

There is no reliable non-destructive method available to determine the gold content of deposits. Usually, the substrate is dissolved chemically or electrochemically and the alloying elements in the remaining coating are analysed by emission or atomic absorption spectroscopy. The gold content is determined by fire assay. Great care has to be exercised to ensure that the gold alloy is not attacked during leaching of the substrate.

Corrosion and Tarnishing Behaviour

Most of the tests used on spectacle frames were adopted from other industries such as automobile manufacture. A general problem with accelerated corrosion tests is that their results do not always agree with the behaviour observed in actual service. The more widely used methods include the following:

CASS test (DIN 50021)

The samples are exposed at 50°C to a copper chloride-acetic acid-salt spray. The exposure time is often 100 hours. Figure 3 shows frames with average gold alloy coating thicknesses of 3 and 5 μm after 100 hours exposure to this test.

Industrial atmosphere test (Kesternich) (SFW 2.0S, DIN 50018)

The samples are kept in an airtight vessel for 8 hours at 40°C in an atmosphere of 0.67 volume per cent sulphur dioxide and are then left in air for 16 hours. This sequence constitutes one cycle. Spectacle frames are usually submitted to 3 successive cycles.

Fig. 3 Spectacle frames, electroplated with 18 carat gold-copper-cadmium alloy ($3\text{ }\mu\text{m}$ on samples 5 and 7, $5\text{ }\mu\text{m}$ on samples 6 and 8), after 100 h exposure to the CASS test

Ammonia test

Samples are kept 48 hours at room temperature in a closed vessel filled with ammonia vapour. Copper alloy substrates are heavily attacked through pores in the gold layer while nickel alloys react only very little. This can be seen in Figure 4. Under a pore in the gold layer a large hole has formed in the copper alloy substrate by reaction with ammonia.

Nitric acid test

Samples are exposed at room temperature to vapours of concentrated nitric acid in a closed vessel. The test pieces are then dried for 5 minutes in air at 105°C and checked visually for corrosion stains. This is a relatively severe test which works well on both copper and nickel alloys. Figure 5 shows temples with gold alloy coating thickness of $3\text{ }\mu\text{m}$ and $5\text{ }\mu\text{m}$ which have been bent by 180° over a mandrel of 10 mm diameter

and straightened prior to the nitric acid test. The bluish corrosion products on the strained part reveal that during deformation the gold layer cracked. In other areas of the temples neither the gold layer nor the base metal were attacked.

Artificial perspiration test

In order to approach as closely as possible actual service conditions the frames are tested in artificial perspiration — a solution of sodium and ammonium chlorides and various organic acids. The testing time is 10 to 15 days between room temperature and 40°C .

Tarnishing test

The resistance to tarnish and the porosity of the gold alloy electrodeposits can be tested simultaneously. For the test the samples are exposed to a 10 per cent hydrogen sulphide atmosphere in a closed vessel.

Fig. 4 Cross section through a temple, electroplated with 18 carat gold-copper-cadmium alloy, after bending, straightening and exposure to ammonia. The copper-based substrate has been dissolved by ammonia which penetrated through a pore in the coating

Fig. 5 Temples, electroplated with 18 carat gold-copper-cadmium alloy ($3\text{ }\mu\text{m}$ on samples 5 and $7,5\text{ }\mu\text{m}$ on samples 6 and 8), after bending, straightening and 2 h exposure to nitric acid vapour. Only the deformed areas of the temples, where cracks developed during bending, are significantly corroded

Various means are used to generate this atmosphere, for instance decomposition of sodium sulphide or thioacetamide or direct introduction of compressed hydrogen sulphide.

Influence of the Substrate Surface Roughness on Corrosion Behaviour

For decorative purposes, the substrate is often given a special surface finish by grinding, sandblasting, brushing or erosion. This strongly affects the corrosion resistance of gold plated parts because the true surface is increased and for a given amount of gold the average coating thickness is decreased. Furthermore, less gold is deposited in crevices and scratches than on ridges and overall the surface tends to corrode easily. Levelling electrolytes are unsuitable for this application, since the decorative effect of surface roughening would disappear during plating.

The influence of substrate surface finish on the corrosion behaviour of gold plated frames can be clearly demonstrated if temples coated with 3 or $5\text{ }\mu\text{m}$ of 18 carat gold-copper-cadmium alloy on original bright substrates or on substrates prepared respectively by disc grinding, sandblasting, abrasive pad brushing or sandpapering are submitted to the nitric acid test (Figure 6). The bright untreated temples are least corroded.

Fig. 6 Temples, electroplated with $3\text{ }\mu\text{m}$ (a) or $5\text{ }\mu\text{m}$ (b) of 18 carat gold-copper-cadmium alloy after 2 h exposure to nitric acid vapour. The substrates had various finishes: bright (1), disc ground (2), sandblasted (3), abrasive pad treated (4) and sandpapered (5). The results of the test clearly show the superior resistance to corrosion of the bright samples. The numerous spotty defects in samples a3 and b3 could be caused by embedded blasting particles

Fig. 7 Cross section through a temple, electroplated with white gold and bent prior to testing in artificial perspiration. Corrosion of the substrate is not restricted to the tip of the cracks in the coating but also spreads laterally underneath the gold layer

Fig. 8 Cross section through a temple, electroplated with nickel and 18 carat gold-copper-cadmium alloy, after bending and 10 days exposure to artificial perspiration. The nickel undercoat is corroded in preference to the substrate alloy

Typical Corrosion Problems on Electroplated Frames

The corrosion behaviour of gold plated spectacle frames is characterised by the fact that a noble metal coating is deposited onto a less noble substrate. Therefore, corrosion only occurs where the coating is defective (cracks, pores, etc.). It is aggravated by the coupling of a large cathodic area of gold with low current density to a small anodic area of base metal alloy with high corrosion current density. This is illustrated in Figure 7 where a white gold deposit, flash coated with rhodium (not visible on the microsection), was cracked by bending prior to being tested in artificial perspiration. The base metal is corroded at the bottom of the cracks with lateral spreading, eventually leading to blistering or flaking

of the gold layer. It should be mentioned here that, due to their sulphur content, bright nickel deposits sometimes have a higher corrosion rate than the substrate material. In the example of Figure 8 the intermediate nickel layer has corroded through a crack in an 18 carat gold-copper-cadmium deposit after 10 days exposure to artificial perspiration whereas the substrate alloy was not attacked.

This brief insight into the manufacture of spectacle frames shows that a properly deposited gold alloy layer can protect them from corrosion and maintain their bright decorative appearance for a long time. However, as in the case of other products, only precise material specifications and careful process control during their production will ensure consistent high quality.

Bibliographies on Industrial Applications of Gold

The growing importance of gold and its alloys in industry has resulted in a considerable increase in the number of papers dealing with research on them or with their applications. A large portion of this literature has been accumulated by the International Gold Corporation Limited and this has facilitated the preparation of bibliographies covering the following subjects:

- Carat gold alloys and their use in the fabrication of jewellery, by W. S. Rapson
- Gold in catalysis, by F. H. Lancaster and W. S. Rapson.

Updated versions of these, as well as bibliographies covering additional fields of gold usage, are planned for the future and will be announced in *Gold Bulletin* as they become available.

Copies of these bibliographies (in standard microfiche form only) may be obtained by writing to the International Gold Corporation Limited, P.O. Box 61809, Marshalltown, 2107, South Africa.