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Electroforming of Optical Tooling in High-Strength Ni-Co Alloy

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Plastic optics are often mass produced by injection, compression or injection-compression molding. Optical quality molds can be directly machined in appropriate materials (tool steels, electroless nickel layers, aluminum, etc.), but much greater cost efficiency can be achieved with electroformed mold inserts. Traditionally, electroforming of optical quality mold inserts has been carried out in nickel, a material much softer than tool steels which, when hardened to 45-50 HR_C usually exhibit high wear resistance and long service life (hundreds of thousands of impressions per mold). Despite their low hardness (<20 HR_C), nickel molds are successfully used to injection or compression mold Fresnel lenses, retroreflective sheeting, conventional spheric and aspheric lenses, various diffractive surfaces, compact discs and other products. However, electroformed nickel inserts usually allow to mold only tens of thousands of impressions before they are scrapped due to wear or accidental damage. This drawback prevented their wider usage in general plastic and optical mold making.

Efforts to improve mechanical characteristics of electroformed items resulted over the years in the introduction of harder electroformable materials, notably nickel alloys. Nickel – Cobalt is known to have higher strength than pure nickel, but higher internal deposit stress in most known alloy plating chemistries prevented their use for optical electroforming where replication fidelity is of paramount importance. Recently, NiCoForm has developed a proprietary Ni-Co electroforming bath combining the high strength and wear resistance of the alloy with the low stress and high replication fidelity typical of pure nickel electroforming. This paper will outline the approach to electroforming of optical quality tooling practiced by NiCoForm and present several examples of electroformed NiColoy mold inserts.

To produce an electroformed mold insert, one must start with an optical original or mandrel. Mandrels for optical electroforming range from diamond turned metal (copper, brass, aluminum) originals to geometries created in glass or other non-metallic materials including photoresist patterns on various substrates. One unique advantage electroforming has to offer is the ability to precisely replicate in a hard and wear resistant metal a pattern (for instance, holographic) that can only be generated in a soft material such as photo resist. This is accomplished by first coating the non-conductive mandrel surface with a thin layer of metal through chemical or vacuum deposition. After metalization, the mandrel is mounted in an electroforming fixture and a replica is created by electrodeposition in a suitable electrolyte. Another benefit of this technology is the ability to replicate sequentially, thus producing generational 'trees' of mold inserts. And so, from a single master a large number of identical mold inserts can be created to inexpensively populate a multi- cavity mold and have spares available in case one needs to be replaced.

For an optical electroform to be usable, several requirements must be met: surface finish, dimensional tolerances and flatness or radius of curvature have to closely match the original, sometimes within a few wavelengths. This can only be accomplished if internal stresses in the electroformed layer are kept to a minimum. Internal stress in an electrodeposit can be explained as the tendency of the deposited layer to either contract (tensile stress) or expand (compressive stress) relative to the substrate upon separation from it. Unless this tendency is minimized, the resulting electroform will dimensionally deviate from the original. A number of factors determine the degree of internal stress in the electroformed layer. Those include rate of deposition, bath chemistry, additives and impurities, agitation. Real-time in tank stress monitoring is necessary to maintain a low level of deposit internal stress. Such techniques have been implemented and perfected at NiCoForm assuring the production of low stress Ni-Co alloy electroforms. Even when average internal stresses in an electroform are kept close to zero, additional difficulties arise from uneven current density distribution across the electroformed surface with protrusions attracting higher current densities. Such effects are mitigated by the use of shields, bipolar anodes, current 'thieves' and other devices. To assure compositional uniformity of the electroform, solution conditions must be controlled within a narrow range –temperature, flow rate, filtration, pH and other parameters are regularly checked and adjusted . The alloy composition is maintained at the desired level by a proprietary electronic controller.

Electroforms produced with the new NiColoy™ process exhibit strength and wear characteristics comparable to hardened stainless and tool steel molds. The alloy can be formed with a hardness of up to 45 –50 HR_C and a tensile strength of up to 1,000 MPa. By varying the alloy composition and process conditions, a range of strength characteristics from the ones listed above down to those of pure electroformed nickel can be obtained. Internal stress in the deposit can be maintained very close to zero or, if necessary, either slightly compressive or slightly tensile. In certain instances, a minimally stressed electroform is easier to separate from the mandrel than a stress-free one. The new alloy in its higher strength condition has high elasticity and low plasticity, which sometimes causes crack formation if the material is subjected to high bending or shearing forces or temperatures in excess of 300 ºC. Nevertheless, with proper care this alloy can be easily machined – ground, turned, milled, drilled, tapped and subsequently mounted in mold blocks.

Since their introduction, NiColoy™ electroforms have been successfully utilized in a number of projects and proven the benefits of the alloy's higher strength both in optical and non-optical applications. NiColoy™ mold inserts are currently used to produce Fresnel lens arrays, diffraction gratings, structured anti- reflective surfaces and other optics-related items. Non-optical applications of this technology include finely patterned foils such as masks, inkjet printer nozzles and SMT stencils, catheter tip-forming dies and selective heavy plating followed by precision machining for mold component repair.