Mechanical Properties of Electroformed Nickel Cobalt Alloys

B. Stein, P. Jaeger and C. Przybyla,
NiCoForm, Inc., Rochester, New York, USA

Abstract

Mechanical properties of nickel-cobalt alloys (0-10% Co) electroformed with low internal stress in sulfamate-based solutions were investigated in as deposited and heat treated conditions. It was demonstrated that alloy properties can be modified by selecting deposition conditions and alloy composition. Recommendations on alloy selection are made based on application requirements.

The higher strength and hardness of nickel-cobalt alloy electrodeposits compared to nickel stimulates their increasing use in electroforming and as engineering coatings. Many advanced electroformed products such as bellows, contacts, optical and nanofluidic molds can only be produced consistently if the deposits' properties are well understood and properly controlled by the process engineer. This paper examines the properties of nickel-cobalt alloys obtained in sulfamate-based electrolytes and, specifically, the relationships between a deposit's composition, internal stress, mechanical properties and thermal stability. Once such relationships are established, the electroformer can use them to tailor the deposit properties to the requirements dictated by the application and assure that produced components will consistently meet their specifications.

Keywords

electroforming, nickel, cobalt, alloy, deposit internal stress, tensile strength, hardness

Experimental

0.0015" - thick foil samples were electroformed on 6" x 6" stainless steel substrates and cut into ½" - wide strips. These coupons were tensile tested on a modified Thwing-Albert QC-1000 tensile tester at a crosshead speed of 0.1 in./min. with the initial gauge length of 4 inches, obtaining the yield and ultimate tensile strengths and elongation of the material.

Hardness was measured on ½" - thick stainless steel blocks plated with at least 0.02" of Ni-Co on a Rockwell superficial hardness tester (Wilson Instruments Mod. 3 JS) with a 15kg load. The average of three readings was taken for each data point in tensile and hardness tests.

Both foil samples and hardness test blocks were electroformed at 1-3 A/Dm^2 in two proprietary Ni-Co alloy electroforming chemistries, one designed for enhanced deposit hardness, the other - for high tensile strength. Deposit internal stress was measured directly in the plating tanks as described elsewhere [1], while tensile and hardness samples were being electroformed. Tensile and hardness tests were performed on samples in the as plated and heat treated (2 hours at the set temperature) conditions. Representative foil samples were chemically analyzed to determine the alloy composition. All samples were deposited in production electroforming tanks equipped with alloy composition controllers in addition to standard controls for temperature, filtration and circulation, solution level and DC power supplies. A qualitative evaluation of the metal's ductility was made after each tensile test by repeatedly folding the strips over onto themselves until they broke.

Results and Observations

Previously described nickel-cobalt alloys [2] were shown to follow annealing patterns known in cold worked metals but shifted to lower temperatures. One of the goals of the present development was to create an alloy that would have greater thermal stability, higher tensile strength and behave like a cold worked material.

The alloys investigated in the current study fell into two distinct groups: one that followed the previously observed trends and annealed to a high elongation, low tensile strength dead-soft material, and the other which upon exposure to temperatures in excess of 600 ^{O}C would completely embrittle. The transformation temperatures for the alloys of the first group were higher than in the earlier study, more in line with what would be expected of a cold worked alloy. Named later High Strength and High Hardness, the two groups of nickel cobalt alloys exhibited properties summarized in Table 1.

Table 1: Comparative features of the high strength and high hardness Ni-Co alloys.

	High Strength	**High Hardness**
Appearance	Semibright	Semibright to Bright
Plasticity	Moderate	Low
Elasticity	Moderate	High
Internal Stress, MPa (lbf/in^2)	< 21 (3,000)	>31 (4,500)
Co Contents, Atomic%	<3	7-10
@ > 750 ^{O}C alloy	Anneals	Embrittles

A typical set of stress – strain diagrams obtained from tensile testing of the prepared foils is shown in Fig. 1.

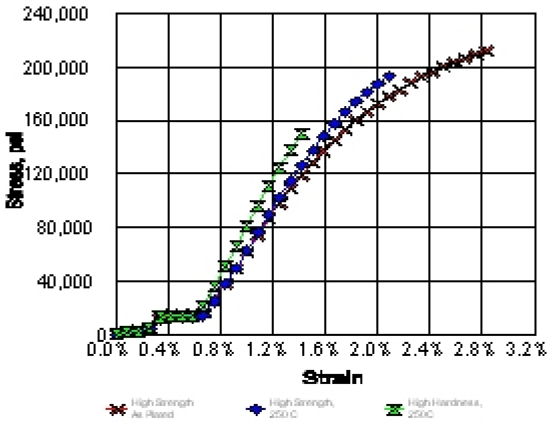

***Figure 1**: Typical Stress-Strain Diagrams.*

It is interesting to note that the as plated high strength alloy exhibits a somewhat greater plasticity and a lower modulus of elasticity than the heat treated to about 250 ^{O}C. The high hardness alloy possesses an even greater Young's modulus. Qualitatively, foils from the more plastic high strength alloy withstood a greater number of bends before breaking (5-10) than the high hardness ones (1 – 2).

The thermal stability of the alloys can be demonstrated by plotting the ultimate tensile strength and hardness of the material vs. the heat treatment temperature as illustrated in Figs. 2 and 3.

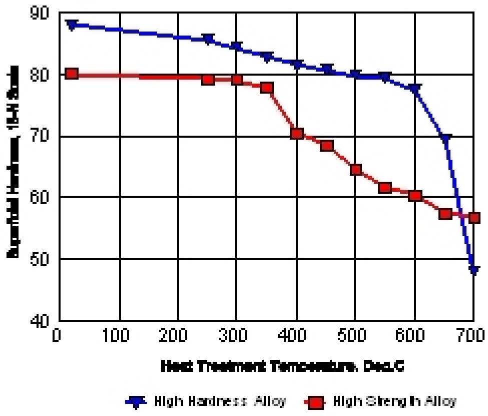

Figure 2
Hardness vs. Heat Treatment Temperature.

The high strength alloy, while exhibiting a lower initial hardness than the harder alloy, begins annealing at about 350 ^{O}C. The high hardness alloy maintains significant hardness up to about 600 ^{O}C but then rapidly embrittles. This difference illustrates the fact that while the lower Co alloy undergoes conventional metallurgical transformations through normalization, recovery to annealing, the higher Co alloy simply embrittles in a fashion similar to that known as 'sulfur embrittlement' in nickel plating. The annealing patterns of the high strength alloy are evident from the changes in the material tensile strength and elongation

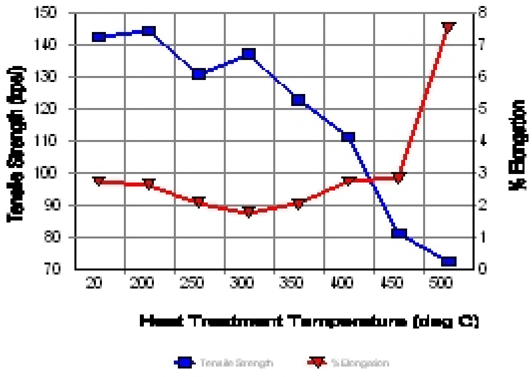

***Figure 3**: Ultimate Tensile Strength and Elongation vs. Temperature.*

(Fig. 3). As the material recovers at about 250-275 ^{O}C, it's grain structure becomes a little more compact and the elongation takes a slight dip. Grain growth during recrystallization at 450-475 ^{O}C causes the tensile strength to decrease while elongation is increasing indicating a complete 'plastification' of the metal. This alloy can be electrodeposited virtually stress-free or with a low tensile or compressive internal stress. The higher hardness alloy usually possesses a moderate tensile internal stress.

Conclusions and Recommendations

Two electroplating baths studied in this paper produce Ni-Co alloy deposits that differ in their mechanical properties and annealing behavior. While the higher tensile strength alloy anneals upon exposure to elevated temperatures, the higher hardness one does not. A summary of mechanical properties of the two alloys is given in Table 2.

Table 2: Mechanical properties of the high strength and high hardness Ni-Co alloys.

	High Strength	**High Hardness**
Yield Strength, MPa (psi)	~ 1,250 (180,000)	~ 1,000 (145,000)
Ultimate Tensile Strength, MPa (psi)	~ 1,350 (195,000)	~ 1,000 (145,000)
Elongation, %	~ 2	~ 1.5

Based on these properties, specific applications can be matched to an alloy which best fits the requirement as is summarized in Table 3. The higher hardness alloy, matching the hardness of stainless and tool steels, is an excellent material for mass production injection and compression plastic molds and catheter tipping dies. The high strength alloy, due to its low internal stress, is used for electroforming of optics and nanofluidic molds. The alloy's high tensile strength and optimal combination of elastic and plastic properties make it suitable for electroforming of bellows, contacts and springs.

Table 3: Recommended Ni-Co alloy chemistry selection for some electroforming applications.

Job Type	**Major Requirements**	**Recommended Type of NiColoy™ Chemistry**
Optics	Zero Stress	High Strength/Low Stress
Plastic Mold Inserts	Wear Resistance/ Hardness	High Hardness
Bellows/ Springs/ Contacts	Elasticity, Dimensional Stability	High Strength
Catheter Tipping Dies	Wear Resistance	High Hardness

References

1. **Conference paper**:
B. Stein, *Fast and Accurate Deposit Internal Stress Determination, Proceedings of the AESF Sur/Fin '2000,* Chicago, IL, July 2000.

2. **Conference paper**:
B. Stein, *Properties of Nickel, Nickel-Cobalt and Copper Electrodeposits for Dynamic Applications, Proceedings of the AESF 30th Aerospace/Airline Plating and Metal Finishing Forum April 5-7, 1994,* pp. 87-94.