LA-UR -91-884

LA-UR--91-884

DE91 009950

TITLE: ELECTRODEPOSITED COATINGS FOR DIAMOND TURNING APPLICATIONS

AUTHOR(S): A. Mayer, MST-6
R. D. Bramlett, MST-6
R. D. Day, MEC-6
C. J. Evans, NIST
R. S. Polvani, NIST

SUBMITTED TO: American Society for Precision Engineering,
Tucson, AZ
April 15-18, 1991

Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

ELECTRODEPOSITED COATINGS FOR DIAMOND TURNING APPLICATIONS

A. Mayer, R. D. Bramlett and R. D. Day
Los Alamos National Laboratory

C. J. Evans and R. S. Polvani
National Institute of Standards and Technology

Electrodeposited coatings are attractive for precision machining operations because thick coatings can be economically applied, with good adhesion, to a variety of substrates. Approximately 20 pure metals and a large number of alloys can be deposited from aqueous solutions. Fused salt and organic solvent electrolytes can be used to lengthen the list of metals that can be electrodeposited. However, both the choice of the metallic coating and the control of the plating process are critical for success in precision finishing of electrodeposited coatings. Some preliminary results at the National Institute of Standards and Technology[1] and at the Lawrence Livermore National Laboratory[2] suggest that electrodeposited nickel-phosphorus alloys are excellent coatings for single point diamond turning from the standpoint of material properties and low tool wear. Electrodeposited aluminum and aluminum alloy coatings also merit consideration for precision finishing where weight is an important factor.

NICKEL-PHOSPHOROUS ELECTRODEPOSITION

Amorphous nickel-phosphorus alloys were first electrodeposited by Brenner et al.[3] These coatings have high hardness[4], good corrosion resistance,[5,6] and dry sliding wear resistance comparable to that of hard chromium.[7] Our interest in NiP was in synthesizing thick metallic glasses for structural characterization and in fabricating free standing electroforms for possible use as unique structural materials. We also were interested in investigating the machining characteristics of these deposits and their resistance to solid-particle erosion.

Amorphous NiP alloys with a composition range of 12 to 15 w/o were electrodeposited from a 125 liter phosphorus acid electrolyte. The solution contained $NiSO_4$, $NiCl_2$, $NiCO_3$, H_3PO_4, and H_3PO_3. The solution was operated at 75°C at a current density range of 5-20 A/dm^2. The pH was maintained between 1.0 and 1.5. We used platinum anodes for most of our work. If soluble nickel anodes are used, the nickel concentration in the solution rises rapidly with a corresponding rise in pH caused by the lower cathode than anode efficiency in this electrolyte. The plating cell had two external filters housings connected in series with course (10 μm) followed by fine (3 μm) cartridge filtration. The filter pump discharge stream was directed towards the cathode to provide vigorous agitation and to minimize particulate inclusions.

An x-ray diffraction scan (Fig. 1) of the NiP deposit shows the material to be a single phase amorphous alloy. A typical TEM image of NiP viewed normal to the deposit surface (Fig. 2) shows no structure. Detailed TEM examination of NiP viewed parallel to the electrodeposited layer (Fig. 3) revealed extremely fine layers on the order of 10-20 μm thick. The light and dark bands are the result of variations in etch rates due to compositional variations within the layers. Amorphous electrodeposited NiP transforms at relatively low temperatures and short incubation times to a two phase material, with intermetallics in a crystalline nickel matrix. These transformations are observed in both electrodeposited and electroless high phosphorus nickel alloys. Figure 4 shows partial crystallization, in the shape of rosettes, of a NiP deposit heated to 265°C for 2 hours. The hardness of the as-plated amorphous phase was 595 DPH while the crystalline phase was 945 DPH. The cracks visible in some of the rosettes in Figure 4 are caused by a volume contraction during crystallization. The hardness and high wear resistance of amorphous nickel-phosphorous coatings suggested that they may also be resistant to solid particle erosion. In our study,[8] NiP and pure electrodeposited nickel was subjected to angular alumina particles at various impingement angles from 15° to 90° at particle velocities from 50-100 m/s. For all experimental conditions, the erosion rate of the amorphous alloy was higher than that of the pure nickel. The material removal in the amorphous NiP was attributed to the formation of plastic shear bands below the impact areas resulting in spallation.

The results of our single point diamond turning experiments showed that thick NiP coatings were essentially pore free and typically showed less tool wear than electroless nickel deposits.[1] Our preliminary results indicate that electrodeposited nickel-phosphorous may be useful for some opto-mechanical applications.

ALUMINUM AND ALUMINUM ALLOY ELECTRODEPOSITION

Practical electroplating processes for active metals such as Al, Mg, Ti, and Be would have applications for both functional and decorative coatings and also for fabricating light weight, high strength structures of high value such as optical components and space hardware. The metals cannot be plated from aqueous solutions because the hydrogen ions of the water are preferentially reduced over the active metal ions. Attempts to plate the active metals from aprotic solvent solutions have been made since the beginning of this century. Of the four metals mentioned above, only organic solvent aluminum plating processes have had limited commercial success.

We were interested in electrodepositing aluminum for electroforming of low Z components and for barrier coatings for metals such as uranium. We selected an aluminum plating process developed by Ziegler and Lehmkuhl[9] for our evaluation. The solutions are based on trialkyl aluminum/alkali metal fluoride complexes dissolved in aromatic solvents. High purity (> 99.99) aluminum deposits with relatively fine grain structures can be obtained from these solutions. Because of the high purity, small grain size, and absence of inclusions in electrodeposited aluminum, high quality mirrors can be fabricated by single point diamond machining. Figure 5 shows a scanning electron micrograph of diamond turned electroplated aluminum. For comparison, diamond-turned commercial grade 6061 aluminum is shown in Figure 6. Chip removal during machining high purity aluminum was difficult. We explored the feasibility of hardening the deposits by alloy plating. We developed plating solutions for depositing Al/Mg alloys spanning the total composition range.[10] The solutions contain trialkyl aluminum/potassium fluoride complexes and dialkyl magnesium dissolved in toluene. A fivefold increase in deposit hardness over the pure Al deposits was observed on an alloy containing approximately 20 at % magnesium. The harder deposits suggest an increase in strength and perhaps improved diamond point machinability. Because some of the organometallic compounds are pyrophoric in air and react violently with water, all operations were carried out in a glove box under positive pressure of dry nitrogen or argon.

SUMMARY

Two classes of electrodeposited coatings were discussed for possible use in precision machining operations. Thick, pore free, high phosphorus content NiP alloy deposits can be electroplated. The high phosphorus electrodeposited alloys appear to extend diamond tool life over that of conventional electroless nickel deposits. The low thermal stability of electrodeposited NiP may preclude its use in some applications. Because electrodeposition of aluminum and aluminum alloys from organic solvent electrolytes are complex processes requiring specialized equipment, the use of these deposits for precision finishing may only be justified for very high value components.

REFERENCES

1. C. J. Evans, R. S. Polvani, and A. Mayer, "Diamond Turned Electrodeposited Nickel Alloys," 1990, Technical Digest Series, Vol. 9, pp. 110-113.

2. J. W. Dini, R. R. Donaldson, and C. K. Syn, "Diamond Tool Wear of Electrodeposited Nickel-Phosphorus Alloy," UCRL-Preprint 102050, Feb. 1990.

3. A. Brenner, D. E. Couch, and E. N. Williams, J. Res. Natl. Bur. Stand. 44, 109 (1950).

4. W. H. Safranek, in "The Properties of Electrodeposited Metals and Alloys" (American Electroplating and Surface Finishing Society, Orlando, FL, 1986), 2nd ed., p. 346.

5. C. Rajagopal, D. Mukherjee, and K. S. Rajagopalan, Met. Finish. J. 82, 59 (1984).

6. M. Ratzker, D. S. Lashmore, and K. W. Pratt, Plating Surf. Finish. 73 (9), 74 (1986).

7. A. W. Ruff and D. S. Lashmore in "Selection and Use of Wear Tests for Coatings," edited by R. G. Bayer (American Society for Testing and Materials, Philadelphia, 1982). p. 134.

8. K. C. Goretta, J. L. Routboard, A. Mayer, and R. B. Schwarz, "Erosion of Amorphous Nickel-Phosphorus," J. Mater. Res. 2 (6), Nov/Dec 1987, pp. 818-826.

9. K. Ziegler and H. Lehmkuhl, Z. Anorg. Allg. Chem., 283, 414 (1956).

10. A. Mayer, U.S. Pat. 4,778,575 (1988).

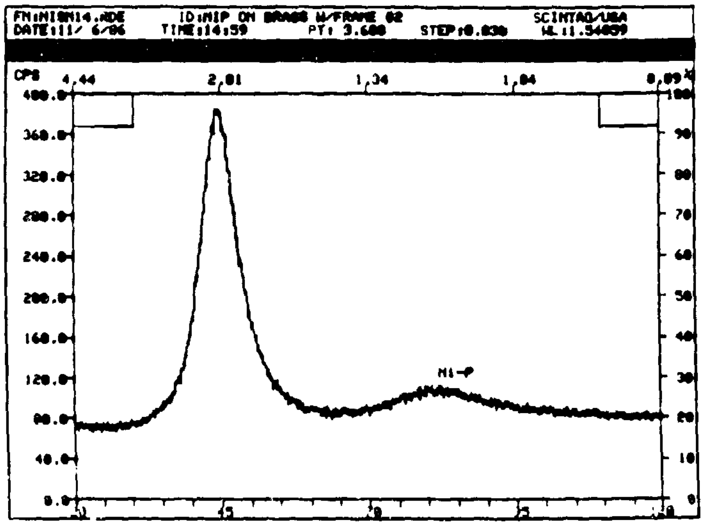

Fig. 1 X-ray diffraction scan of electrodeposited nickel-phosphorus alloy.

Fig. 2 TEM of NiP alloy surface viewed normal to the deposit layers (parallel to growth direction). Crack occurred as a result of thinning during specimen preparation.

Fig. 3 Dark-field TEM photograph shows cross section of NiP alloy viewed parallel to electrodeposited layers (normal to growth direction).

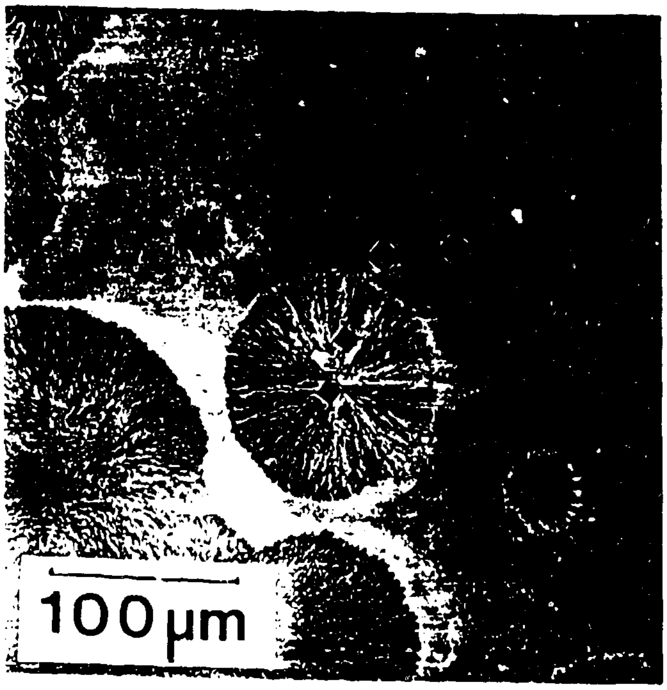

Fig. 4 Rosettes formed by partial crystallization of amorphous NiP when heated to 265°C for 2 h.

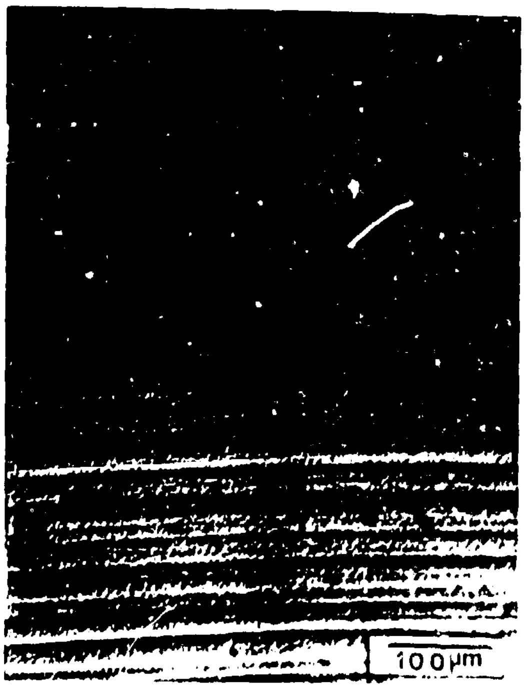

Fig. 5 Micrograph of surface of diamond-turned aluminum deposited at 1 A/dm^2 with a 10 percent duty cycle. Plating thickness before machining was 75 µm.

Fig. 6 Micrograph of surface of diamond-turned commercial-grade aluminum. Pits are probably result of removal of inclusions in aluminum alloy.