Composite Coatings Utilizing Magnetically Fixed Particles

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Composite coating is one of the methods to form films of composite materials utilizing electrodeposition. The electrodeposited film with co-deposited particles is augmented with additional functions which cannot be possessed by the matrix metal film alone. In general, composite coatings are formed by electrodepositing the matrix metal films co-deposited with particles from their suspended solutions. Homogeneity and amount of particles in the films, and the stability of suspended solutions depend on the characteristics of the particles and the matrix metals, so it is not easy to find the optimum condition to control these properties simultaneously. To overcome this problem, we have investigated a new method to form similar composite structures without using suspended solutions; the particles mixed with magnetic particles are fixed on the electrode by the attractive force from the magnets placed on its back side, and then, their gaps are filled with electrodeposited metal. Here, we call this method as composite coatings utilizing magnetically fixed particles (CCMFP). In this paper, we investigate alumina co-deposited nickel composite coatings as a model case of CCMFP, and show some necessity conditions to realize the formation of composite coatings by this method.

As a preliminary test, we tried to find the suitable condition for filling the gaps between nickel particles magnetically fixed on a copper working electrode with electrodeposited nickel without using alumina particles. Conventional Watts bath, which is one of the simplest nickel plating solution, was used as the electrolyte solution. The magnets for fixing the nickel particles were two types of neodymium magnets, we call them magnet A and B; the magnet A has the magnetic flux density of 360 mT with the size of 15×10×5 cm^3 and the magnet B is a bundle of small magnets having the magnetic flux density of 213 mT with the size of 1×1×5 cm^3 (total size: 16×14×5 cm^3). (Fig. 1) Electrodeposition using magnet A, however, did not result in the formation of a uniform film. One reason was that nickel was electrodeposited mainly on the nickel particles not on the copper electrode due to the conductivity of nickel particles. This problem was overcome by increasing the contact resistivity between each particle with thermally-formed nickel oxide. Another reason was non-uniform distribution of the magnetic field, and that was evaded using the magnet B with a bundle structure. After improving these two issues, bottom-up growth of electrodeposited nickel was achieved, but even so, the roughness of the film did not improve. We thought this was because the bottom-up filling of nickel slowed down during the electrodeposition process due to the recovery of conductivity between nickel particles by the dissolution of nickel oxide. To investigate the stability of the oxide, we performed electrodeposition using solutions with different pH values; then electrochemical measurements and thermodynamic estimations revealed that the nickel oxide was easily reduced at low pH, and moderately high pH without forming precipitates of nickel hydroxide in the solution was suitable for continuing uniform bottom-up filling. Nickel-alumina composite coating was conducted under the optimized condition written above, and it was successfully formed. (Fig. 2) Although the surface roughness of the composite film and uniformity of dispersion of alumina particles need further improvement, the results demonstrate the possibility of CCMFP as a potent method for the formation of composite coatings.

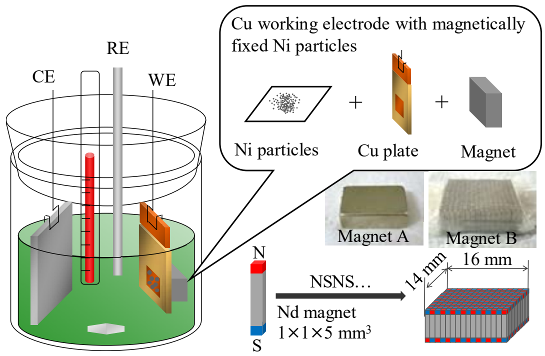

Fig. 1 Experimental setup of the three-electrode electrochemical cell for CCMFP with a Cu plate working electrode with magnetically fixed Ni particles, a Ni wire quasi reference and a Ni counter electrode. Photos of the magnet A and B, and the schematic structure of the magnet B are also presented.

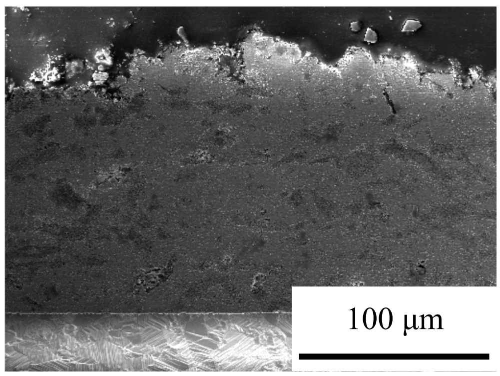

Fig. 2 Cross-sectional SEM image of Al_2O_3-Ni composite film formed by CCMFP; darker gray parts are included Al_2O_3 particles.