Electro Co-deposition and Characterization of SiC in Nickel Metal Matrix Composite Coatings on Aluminium 7075

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Abstract

In this work, mechanical properties viz., wear resistance, hardness, scratch resistance of electrode deposited Nickel with SiC on Aluminium 7075 are discussed. Electro codeposition of MMC coating has been influenced by many factors viz., current density, voltage, percentage of particle concentration, addition of surfactant and bath composition which are also conferred. Elaborate study has been dispensed on these factors to search out the optimum parameters. The state of art has been discussed for co deposition process of SiC with nickel.

Keywords: Aluminium 7075, Electro Co-deposition, Metal Matrix Composites, SiC.

1. Introduction

Increasing applications in aerospace and allied fields of aluminium 7075 is due to the inherent properties like lightness and good strength-to-weight ratio. It replaces many metals in applications where weight is considered as a major factor since its density is one third of the steel. As one of the important applications, Aluminium 7075 is employed in aerospace structural fastened joints where wear and fatigue damages can cause catastrophic failures under fluctuating loads [1-5]. Some aluminium 7075 based parts like engine pistons, working under fairly high temperatures and wearing conditions needed surface treatment to increase the wear resistance and to lower the friction coefficient.

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Significant interest on electrodeposition of nickel on aluminum 7075 has increased considerably due to the fact that the coating can eliminate the disadvantages of uncoated aluminum to some extent [3-7]. This is the reason why nickel plating is widely used in automotive industries for reducing wear of the engine parts [8-10]. To enhance material properties such as wear resistance, lubrication, corrosion resistance metal matrix composite coatings are produced by electro depositing the fine particles of micro and nano size metallic, non metallic materials along plating [6-10]. Nickel which possesses high tensile strength and good toughness is a popular choice as a matrix material and also it can disperse both soft and hard reinforcements. When compared to pure metal or alloy, hardness, wear and corrosion resistance are improved in electro codeposited metals or alloys [11-15].

Electro-codeposition method is more advantageous when compared to other coating methods like high velocity oxygen fuel (HVOF), thermal spraying, hot isostatic pressing, due to the ability of continuous processing, capability to handle complex geometry, normal working pressure, quick deposition, homogeneous distribution, low maintenance and reduced waste generation [16-17]. Electro-codeposition is an effective method to produce Metal Matrix Composite (MMC) coatings through codepositing metallic, non-metallic particles with pure metals or alloys through which the tribological properties and corrosion resistance can be improved [18]. In the current scenario, research on codepositing ceramic particles such as SiC, Cr2O3, TiO2, Al2O3, and WC along with nickel plating finds a platform to improve the wear resistance of plated component [6-20]. It is apparent that these tribological properties mostly depend on the amount, size and distribution of reinforced particles [21-22]. The surface morphology has also been affected by the electroplating parameters such as bath composition, current density, temperature, pH and stirring speed [23]. The literatures report that Ni/SiC composite coatings exhibit better wear resistance as the percentage of weight of SiC increases. The presence of SiC particles in the nickel composite coatings disturbs the regular growth of nickel crystals and causes inter crystalline bonding [24]. Recent studies revealed that codeposition of micro sized particles homogeneously in the deposit are highly complicated because of the higher tendency of particle agglomeration. Non-homogenous electro-codeposition leads to decrease the wear resistance of the coated substrate [25]. Hence more attention is required to attain the homogeneous distribution of reinforced particles in near non agglomerated form. Henceforth, the aim of this work is to produce harder Ni / micro SiC composite coatings with higher resistance to wear.

2. Experimental Setup

The electro-codeposition process was done in the experimental setup developed specially for this research work. The schematic diagram of the setup is shown in fig.1. The experimental setup consists of a plating bath, step down transformer, micro controller and the display panel. The plating bath was fabricated by sheet metal and it was coated with fiber reinforced plastics to ensure the non-conductivity of the electric supply. The bath was equipped with a heating filament which was used to heat the plating solution to the required temperature. The alternating electric supply was brought down from 230V to 12V by the step down transformer. Bridge rectifier coupled with filter was used to convert the AC supply to DC supply. This setup was controlled by a micro controller, designed for this research work through which both direct current and pulse current with varying duty cycle can be generated. Along with types of current, temperature, voltage, current density and stirring speed were also controlled by micro controller. The constructed experimental setup is shown in fig.2. The flow chart of the microcontroller is shown in fig. 3. The standard Watt’s nickel sulphate bath was used for electroplating. The surfactant, Sodium Dodecyl Sulphate was added to avoid the agglomeration of the micro particles [26, 27]. Literatures reveals that even the stirring speed has the effect on the particle codeposition in the MMC coatings [28]. Hence, in addition to the surfactants, stirring at constant speed using mechanical stirrer was used to maintain the homogeneity of the dispersed micro particles. The bath was stirred for minimum of one hour using stirrer before the coating in order to avoid the particles to get agglomerated at the bottom of the bath.
Fig. 1. Schematic Diagram of Experimental Setup

Fig. 2. The Experimental Setup
Fig. 3. Flow Chart of Micro Controller

Table 1. Chemical composition of the bath and the parameters of electrodeposition.

| Electrolyte (Watts' type)     | Concentration (gL-1) |
|-------------------------------|---------------------|
| NiSO₄·6H₂O                    | 300                 |
| NiCl₂·6H₂O                    | 50                  |
| H₃BO₃                         | 40                  |
| Silicon Carbide (SiC)         | 5,10,15,20          |
| pH                            | 4                   |
| Temperature (°C)              | 60°C                |
| Current Density (A/dm²)       | 0.5 - 2             |
| Stirring Speed (rpm)          | 250 - 650           |
3. Electro Co-deposition Process.

Electro co-deposition of nickel with SiC on aluminium travels a long process because nickel coating cannot be done directly on aluminium substrates. Hence the substrates have to undergo preliminary preparations before codeposition. Aluminium substrates are first machined to the ASTM standard size of 10mm diameter and 20mm height. After machining the substrates were polished with sand paper till 2000 grit size. The polished substrates were first degreased in 42 g/L NaOH solution at 65°C for 20 seconds. Further the substrates are cleaned in distilled water and they were coated with zinc through electro less plating process (Zinc oxide 100g/L, Sodium hydroxide 525 g/L, ferric chloride 10g/L and Sodium tartate 1 g/L). Zincated substrates were then copper plated for 30 seconds and again washed in distilled water before the codeposition of nickel with SiC is done [29]. A nickel plate of 99.9% pure and of 30 mm X 35 mm dimensions is used as anode. It was cleaned properly to remove the oxide layers. The freshly prepared electrolyte as per the table 1 is employed for fabrication of codeposited samples. The SiC is dispersed in form of paste and mixed to maintain the homogeneity using stirrer for minimum of one hour before the electro-codeposition. The SiC powder of 99.9% pure with mean diameter of 2-3μm was added in the bath in form of paste which was prepared by blending SiC with little electrolyte. The pH of the plating bath was maintained to 4.0 ±0.1 in all conditions. The current density of 2 A/dm², voltage of 2V and temperature of 60°C were constantly maintained for all samples. Both Direct Current and Pulse Current with 50% duty cycle were employed to coat the samples. The coated samples shown in fig. 4 were ultrasonically cleaned in ethanol for 10 minutes to remove loosely adsorbed particles from the surface. To maintain a constant coating thickness, the time of coating was varied accordingly for each sample. The composition of percentage weight of SiC was varied between 0g/L to 20g/L for both Direct Current and Pulse Current. The samples were then prepared accordingly for the requirement for each test. The coated samples were examined and the reinforcement of micro SiC in the nickel matrix was confirmed.

![Fig. 4. Coated samples by varying SiC concentration in bath.](image-url)
4. Results and Discussion

4.1. Effect of addition of SiC particles

The codeposition of SiC particles in the nickel MMC has relationship with the current density, addition of surfactants, stirring speed and concentration of SiC in the plating bath. The optimum values of these variables of the bath were determined after several hit and trial attempts. The smooth coatings as well as the codeposition of SiC were achieved under the condition of 4.0 pH, 60°C temperature, 2 A/dm² current density and 0.2 g/L surfactant. Keeping all these optimized parameters as constant, the concentration of the SiC in the plating bath were been varied based on the table II and the samples were prepared for analysis. The samples were then machined for SEM analysis. Surface morphology of the electro-codeposited samples were done using SEM [JEOL-JSM-6610LV] machine at different magnifications. The surface morphology of the samples prepared by Direct Current was shown in fig. 5(a-e). The fig. 5 (a) shows the pure nickel coating and fig. 5 (b),(c),(d),(e) shows the codeposition of SiC with nickel in 5g/L, 10 g/L, 15 g/L, 20 g/L under the application of Direct Current. The reinforcement of SiC in the nickel matrix was confirmed and the size of SiC incorporated in each codeposited samples were measured and it coincide with the size of micro SiC blended in the plating solution. An ionic cloud around SiC particles are formed because of the adsorption of nickel ions on the SiC particle surfaces. This ionic cloud size decides the deposition rate, i.e. more the size higher the deposition rate. The entrapment of SiC particles between the Ni matrix can happen only when the it clung to the cathode surface for sufficient period. The weight percentage of SiC particle in the coating increases linearly when the concentration of SiC in the bath increases and decreases rapidly when the concentration of SiC in the bath further increased beyond the optimum level. It is apparent that the decrease in weight percentage of SiC beyond the optimum concentration of SiC in plating bath is due to the agglomeration of SiC particles. This agglomerated SiC particles move slower than the metal ions towards the cathode. Agglomeration of SiC particles not only reduces the incorporation but also leads to heterogonous coatings. In composite electrodeposits, the actual current density is considerably higher than the apparent current density since the SiC particles occupy the sites available for nickel deposition [27]. Hence the moderate low current density is preferred to obtain homogenous deposits. The time required to obtain the required thickness is more in low current density when compared with high current density.

4.2. Micro Structural Analysis

The influence of SiC content in the plating bath on the deposition rate and the codeposition of SiC are discussed in this topic. The SEM images shown in fig.5(b-d) clearly shows the homogenous codeposition of SiC in the nickel MMC coatings. But in the fig.5(e), the SiC was incorporated with lots of agglomerations. Even the coating obtained

| Sample Number | Additives       | % Wt of Micro SiC of Size 2-3 μm | Stirring Speed in RPM |
|---------------|----------------|---------------------------------|-----------------------|
| 1             | Without surfactant | 0 g/L                           | 250                   |
| 2             | Without surfactant | 5 g/L                           | 250                   |
| 3             | Without surfactant | 10 g/L                          | 250                   |
| 4             | Without surfactant | 15 g/L                          | 250                   |
| 5             | Without surfactant | 20 g/L                          | 250                   |
| 6             | With surfactant   | 0 g/L                           | 250                   |
| 7             | With surfactant   | 5 g/L                           | 250                   |
| 8             | With surfactant   | 10 g/L                          | 250                   |
| 9             | With surfactant   | 15 g/L                          | 250                   |
| 10            | With surfactant   | 20 g/L                          | 250                   |
in 20 g/L concentrated bath is heterogeneous. The tribological properties and the microhardness are enhanced only when the surface is homogenously incorporated with SiC. Hence it is apparent that the heterogeneous nature of the produced surface will definitely decrease the tribological properties of the coated substrate. Since the particle transfer is always slower than the metal ions which lead to decrease of the concentration of the adsorbed particles at the cathode surface, the adsorption become negligible. However, this problem can be avoided to a limit by stirring the plating bath with a stirrer. Mechanical stirrer with 250 RPM was employed in this research work to avoid the agglomeration and particle sedimentation under the plating bath. For further improvement, Sodium Dodecyl Sulphate was added as the surfactant. The addition of surfactant in the plating bath increases the codeposition of SiC and also avoids the agglomeration of the suspended particles by increasing the positive zeta potential of the suspended SiC particles.
5. Conclusions

Codeposition of micro SiC of size 2-3 μm in the nickel MMC coatings were successfully performed using electro plating method. The influence of the concentration of SiC particles in the bath and the addition of surfactants on the codeposition process of SiC along with Nickel was investigated. The SEM micrographs were captured and it reveals the effect of the addition of SiC in the MMC coatings. The increase in concentration of SiC in the bath increases the codeposition in nickel matrix till 15 g/L concentration of SiC in the bath and it reduces beyond the optimum level. The addition of surfactant increases the codeposition and maintains the homogeneity of coating. From the results it can be hereby inferred that the optimization of the % volume of SiC dispersed in the bath also leads to yield the uniform coating and maximizes the codeposition.

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