Use of a 3D printed auxiliary module for the quality improvement of Ni-P/SiC nanocomposite coatings

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INTRODUCTION

Ni-P/SiC composite electroplated coatings are considered as one of the most cost-effective and best-performing combinations that could replace hard chromium coatings, due to their excellent microhardness, as well as wear and corrosion resistance. These properties depend, among others, on the phosphorus content of the Ni-P matrix and the amount, distribution and particle size of the embedded SiC nanoparticles (NPs) [1].

Ni-P/SiC coatings can be divided in three main categories: low (1-5%), medium (5-8%) and high phosphorous content (above 9%) [2]. Pillai et al. observed that the incorporation of phosphorous in the nickel lattice can reduce the nickel grain size from microns to nanometers.[3] In addition, the utilization of pulse current electroplating has been shown to improve the quality and the properties of the Ni-P/SiC coatings [4, 5].

Nevertheless, the electroplating process also depends on other factors such as the design and actual set-up of the electroplating cell, the hydrodynamic conditions and the positioning and geometrical characteristics of the anode and the cathode.

In this work, the modification of the electrolytic cell set up by designing and printing a plastic auxiliary module, made by ABS with the aid of a Fused Filament 3D printer is presented. This module was installed in the bath to alter the hydrodynamic conditions in the area of the cathode. The effect of the current density and the duty cycle on the pulse current Ni-P/SiC electrodeposition was subsequently investigated.

METHODOLOGY

As mentioned above one of the min challenges is Ni-P/SiC electroplating is the hydrodynamic conditions. For that reason, a barrier designed and printed in order to ''break'' the homogeneous magnetic stirring, assist in the better dispersion and movement of the particles in the electrolyte and facilitate the incorporation of them in the metal matrix.. Following that, coatings produced, with and without the 3D printed barrier, compared and finally the whole`s electroplating cell parameters optimized.

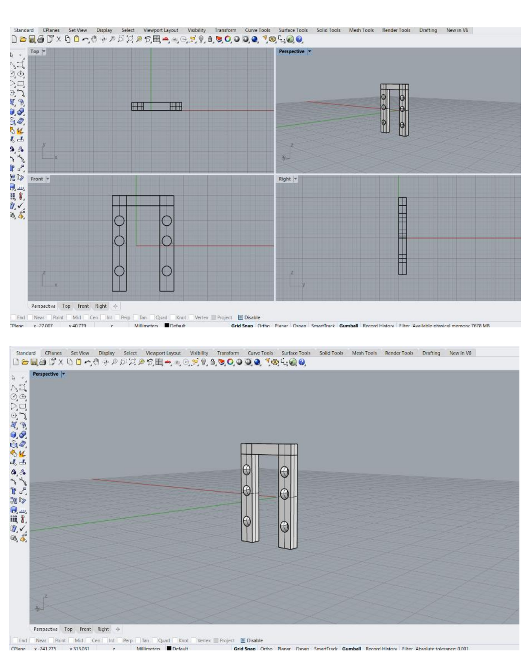

Figure 1. 3D designing in Rhino 3D

Figure 2. Printing and installation

Table 1. Ni-P/SiC electrolyte bath composition and Electroplating conditions

Ni/SiC electrolyte	g/L
$NiSO_4 \cdot 6H_2O$	260
$NiCl_2 \cdot 6H_2O$	48
H_3PO_3	40
H_3PO_4	20
Saccharin	2
SDS surfactant	2.5
SiC NPs	10
Operating conditions	
pH = 2, T = 50 °C, Pulsed current with 20, 30, 35, 37and 40 % duty cycle, f = 10 Hz, Current density= 2, 2.3, 2.5, 2.7 and 3 A/dm^2 , t = 5 h	

RESULTS

Various measurements were performed to validate the efficiency of the barrier assisted electroplating cell. The properties of the produced coatings were evaluated by optical microscopy and Vickers microhardness measurements. The Si content was determined with a portable XRF analyzer. Moreover, DLS measurements were also performed to investigate the SiC particle size during the plating process. Results show that the introduction of the 3D printed auxiliary module resulted in a more uniform and dense co-deposition of SiC NPs in the Ni-P matrix which in turn led to a substantial enhancement of the Vickers microhardness of the produced Ni-P/SiC nanocomposite coatings.

Comparison of coatings w and w/o 3D printed barrier

The optimum parameters for the electroplating process according to the above study is: duty cycle 37%, f=10Hz and current density 3 A/dm^2 . In the optimum synthesis a comparative study performed in order to investigate the contribution of the barrier in the distribution of the particles in the surface and in the SiC incorporation in the metal matrix. The results presented below, and it is clearly observed that the 3D printed barrier plays a prominent role in the properties of the final product.

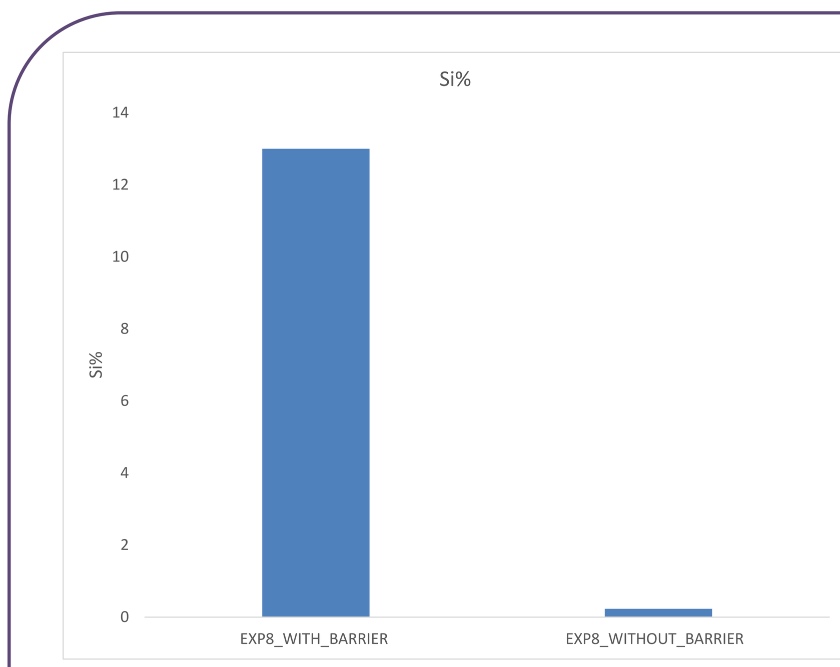

Figure 3. Comparison of silicon content in Ni-P/SiC coatings w and w/o 3D printed barrier

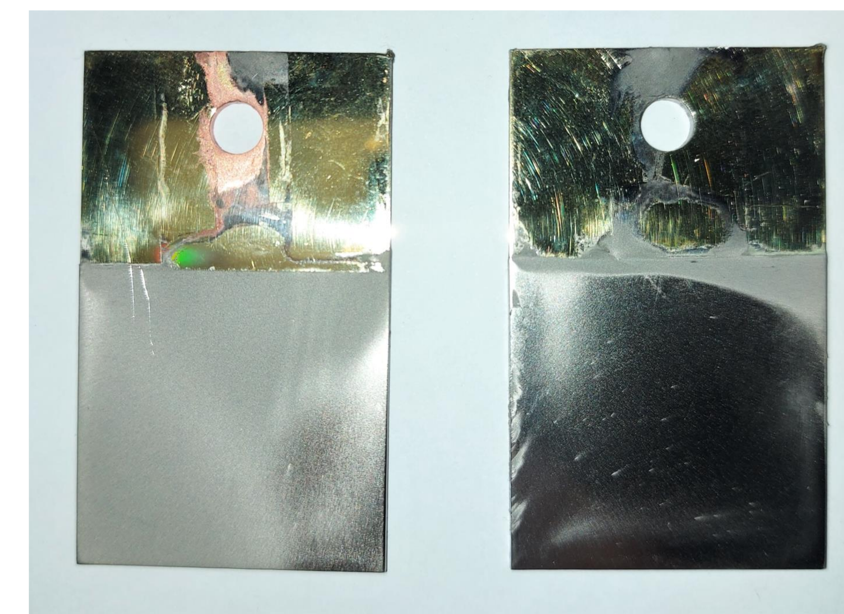

Figure 4. Comparison of images captured from coatings produced w and w/o the 3D printed barrier

Optimization of plating parameters

After the establishment of the critical contribution of the 3D printed barrier, the plating parameters were optimized. Firstly, five different values for the duty cycle and the current density were examined. Moreover, particle size was measured during the process to investigate the aggregation rate. Optical microscope images were captured to examine the surface morphology of the the Ni-P/SiC coatings at x100 magnification. The microhardness and the SiC content was evaluated. The results are presented below.

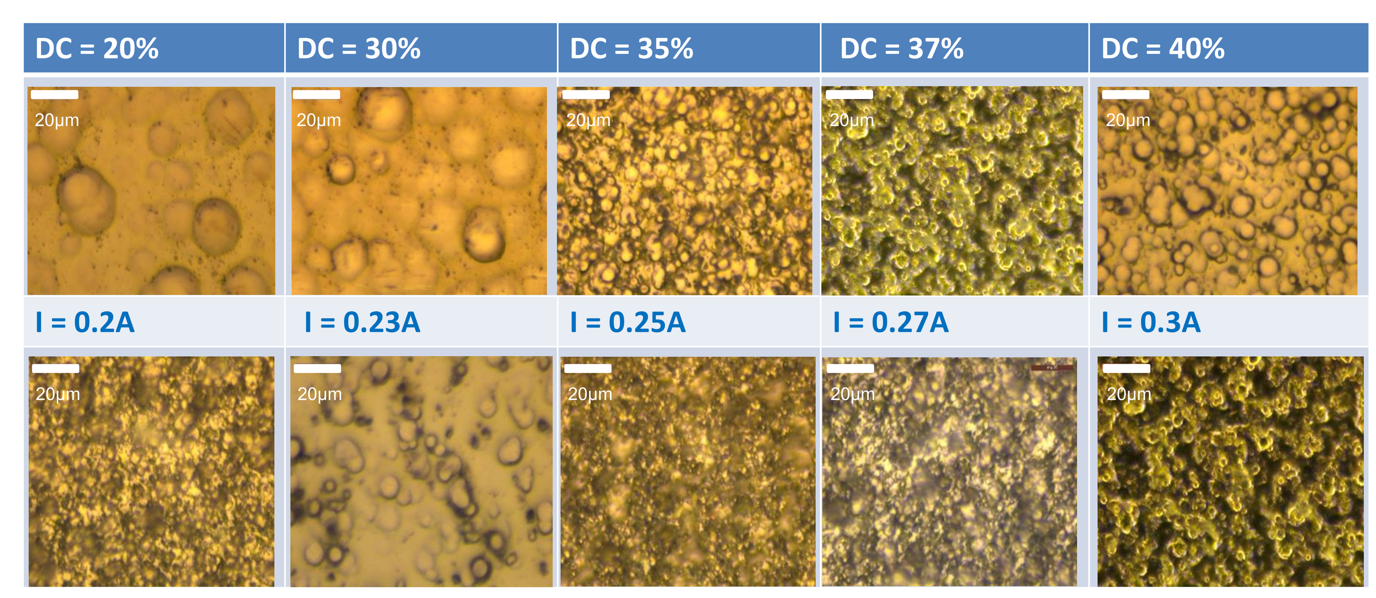

Figure 5. Optical microscope images (100x) of Ni-P/SiC coatings at (a) 20% (b) 30% (c) 35% (d) 37% and (e) 40% duty cycle at (f) 0.2 (g) 0.23 (h) 0.25 (i) 0.27 and (j) 0.3 A/dm² current density.

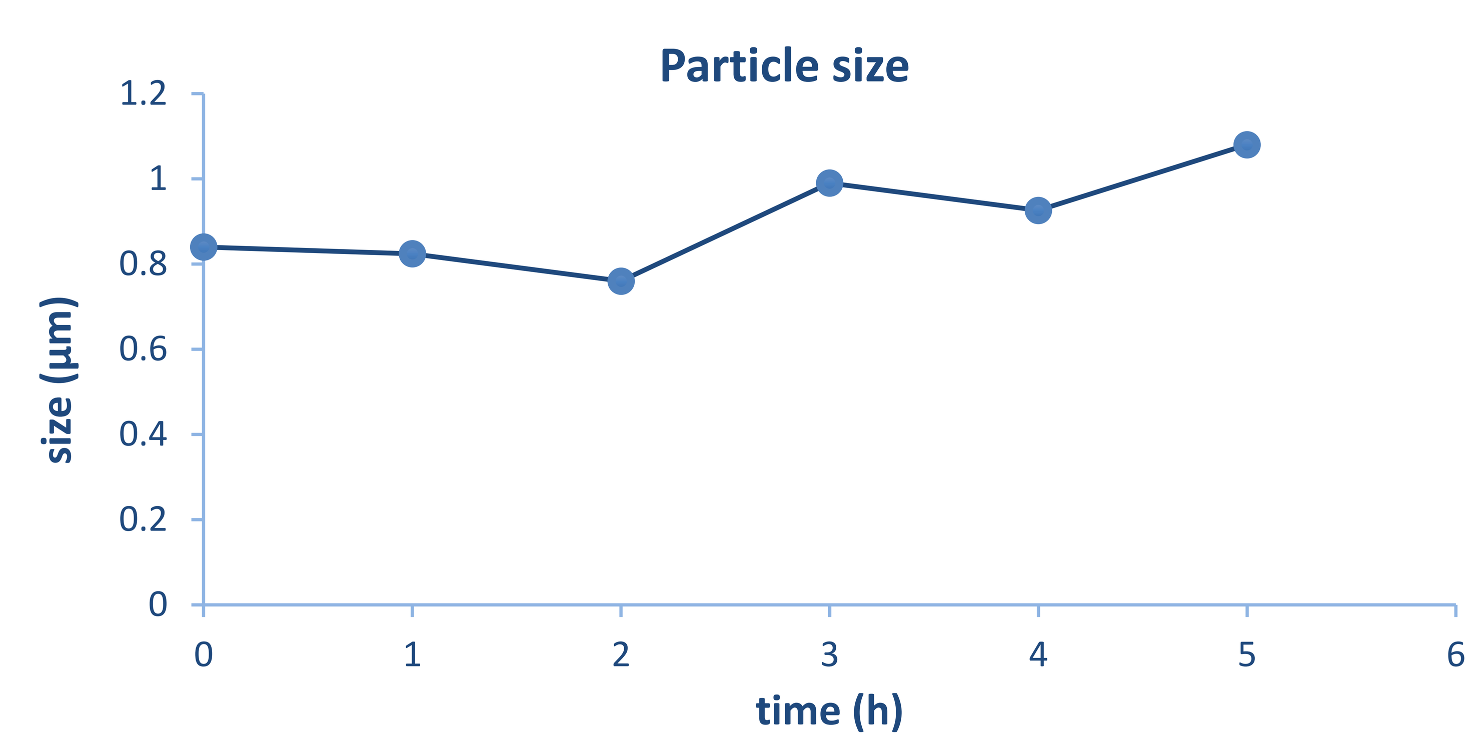

Figure 6. Measurement of SiC particle size during a 5h electroplating process.

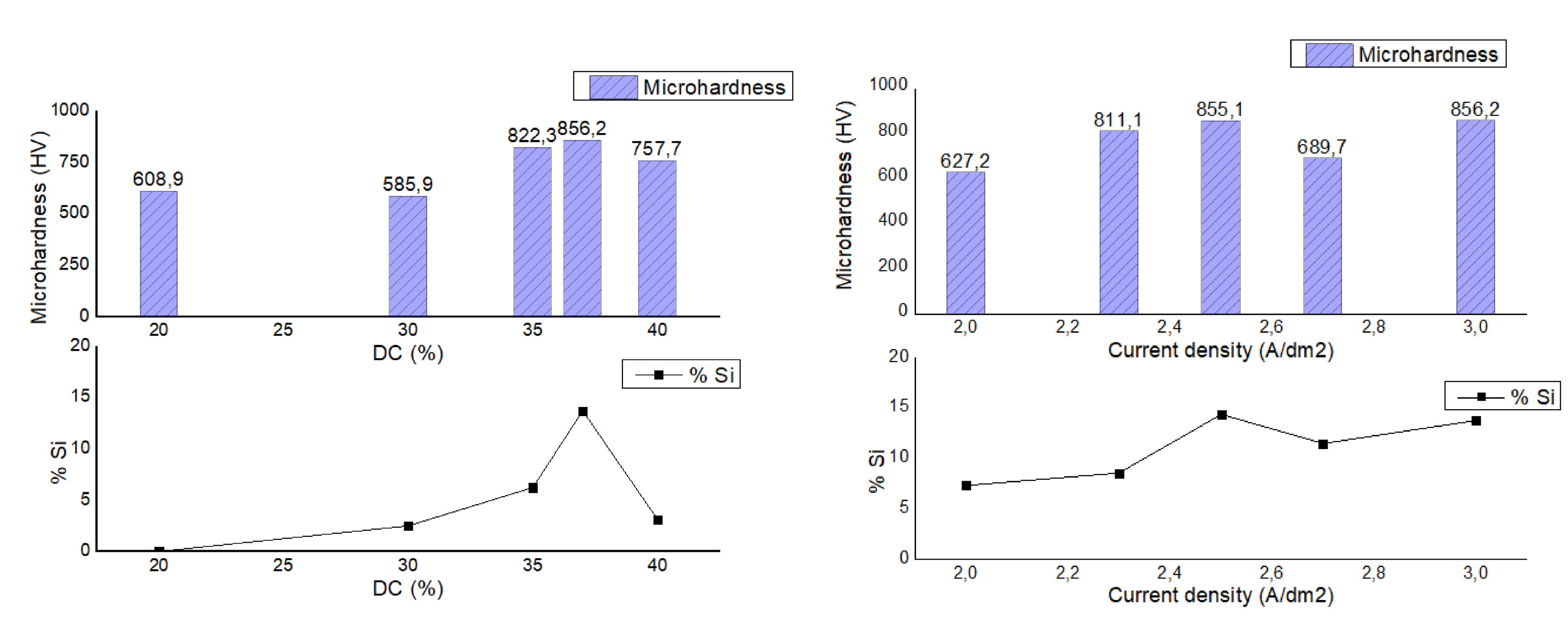

Figure 7. Microhardness and SiC content versus duty cycle (left) and current density (right)

CONCLUSIONS

- A 3D printed barrier designed and printed using ABS filament in a FFF 3D printer was used to improve hydrodynamic conditions during electroplating.
- The 3D printed barrier enhances the incorporation SiC NPs in the Ni-P metal matrix.
- Optimization of duty cycle and current density in Ni-P/SiC electroplating produced the best Ni-P/SiC coating at f = 10 Hz, duty cycle = 37% and current density= 3 A/dm^2
- A microhardness of 865 HV was obtained.

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