

RECIPROCATING SLIDING SPEED EFFECT ON THE TRIBOLOGICAL PROPERTIES OF SiC_p REINFORCED Ni MMC_s DEPOSITED BY ELECTROPLATING

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Abstract

In the present work, Ni/SiC metal matrix composite (MMC) coatings were prepared from a modified Watt's type electrolyte containing nano-SiC particles by direct current (DC) plating method to increase wear resistance of Ni. The influence of surfactant content on co-deposition of SiC particles (0.1-1.0 μm size range) in the matrix, and tribological properties were investigated. The influence of sliding speed on the tribological performances of the coatings was investigated by a reciprocating ball-on disk apparatus. The wear tests were carried out at different sliding speeds by using a constant load. Wear resistances and friction coefficients of Ni/SiC composites were decreased by increasing sliding speed because of temperature-controlled surface oxidation. The change in wear mechanisms by changing surfactant content and sliding speeds were also comprehensively studied and, in general, decreasing surface damage was obtained by increasing sliding speed.

1. Introduction

Electrodeposition is one of the most technologically feasible and economically superior techniques for fabrication of metal matrix nanocomposite coatings. In general, the nanocomposite coatings have better microhardness as well as wear resistance [1-4]. Nanocomposites and coatings are among the most exciting and fastest-growing areas of research. Therefore, they offer enormous potential for new applications, including: aerospace, automotive, electronics, biomedical implants, mechanically reinforced lightweight materials, sensors, nano-wires, bioceramics, batteries, energy conversion and many others [5-8]. Recently, the main work carried out in this field is aimed almost entirely to the fabrication of wear- and corrosion-resistant coatings, and dispersion- strengthened coatings [9-11].

Nickel has been used by many researchers as matrix metal for depositing composite coatings on a metallic substrate. For example, a number of studies have been published on research work, which dealt with the deposition of the nickel matrix composite coatings, reinforced with the different kind of nano ceramic particles such as Al₂O₃, SiC, Cr₂O₃, TiO₂, MoS₂, WC, ZrO₂, SnO₂ diamond, etc. on several substrate metals [8, 12-20]. The structure of coating becomes increasingly more finely crystalline [15, 21]. Jiaqiang et al. [22] have found that the crystallization temperature of the composite coating decreased due to the incorporation of

nanometer ceramic particles. The good wear resistance mainly results from the fine-crystalline microstructure and the increased microhardness [15, 23].

In this work, the composite electrocodeposition method has been used to fabricate the nickel matrix composites reinforced with SiCp. Although there are several studies on the wear of Ni-SiC nanocomposite coatings, there is no such specific study to investigate particle size distribution and sliding speed in Ni-SiCp coatings. Since decreasing size of second phase particle size does not effectively contribute the wear performances of MMCs, SiC particles were chosen in a wide size range to obtain both hard and wear resistant Ni/SiC MMCs.

2. Experimental Procedure

The plating electrolyte used for the process was a Watt's type electrolyte. The electrolyte bath is composed with 300 g/l Ni₂SO₄.6H₂O, 50 g/l NiCl₂.6H₂O, 40 g/l H₃BO₃, 0.2 g/l Sodyumdodecyl sulfate and 20 g/l SiC. The electrolyte temperature coating was controlled at 45 °C (±2) and the pH was fixed at 4 (±0.2). The range of SiC particle size used in the experiment was 0.1-1 µm. A Ni plate of 30 mm x 35 mm was used as an anode, and a stationary iron substrate was used as a cathode. Cetyltrimethylammonium bromide (CTAB) was used in the experiment as a surfactant. The amount CTAB used as a surfactant in the electrolyte was studied at 0 mg/l, 100 mg/l, 200 mg/l, 300 mg/l and 400 mg/l respectively. Prior to deposition, zeta potential of the nano-particle suspended solution was measured with Malvern Zetasizer Nano Series Nano-ZS model instrument. The process steps are preparation of electrolyte with suspended nano-particles, magnetic stirring for 20 h at 400 rpm, ultrasonically agitation for 0.5 h and performing electro co-deposition at current density of 3 A/dm² for 2 h. The depositions were controlled to obtain the coatings in specific thickness (between 50 – 200 µm) and particle volume fraction in the matrix (between 0.03 and 0.11).

After co-deposition, a scanning electron microscope (SEM, JEOL - JSM 6060 LV) was used to observe the surface and the cross-sectional microstructures of the deposits. X-ray diffractometer (XRD) analysis was carried out with a rigaku D/MAX/2200/PC model XRD system scanning at a speed of 1°/min in the 2θ range of 10 -100°. The hardness of the coatings was measured using a Vicker's microhardness indenter (Leica VMHT) with a load of 50 g. The reciprocating tribological behaviors of the coatings sliding against an M50 steel ball (Ø 10 mm) were examined on a Tribometer (CSM Instruments) designed according to DIN 50 324 and ASTM G 99-95a in a ball-on-disk configuration. The wear tests were performed at a constant applied load of 1.0 N with sliding speeds of 50 mm/s, 100 mm/s and 150 mm/s. The SEM and 3D profilometry (KLA Tencor P6) was used to study the morphologies of the wear tracks. The particle volume fractions were calculated from the SEM image analysis program which based on phase area method.

3. Results and Discussion

3.1. Effect of surfactant content on the SiC distribution

Increasing the surfactant concentration in the electrolyte resulted in increasing the amount of the nano ceramic particles, which were also confirmed by SEM analysis. Fig.1 shows the cross-sectional SEM microstructures of Ni/SiC nano composites. The results showed an increment of the nano particles in the deposited Ni layer by increasing surfactant concentration in the electrolyte. The amount of co-deposited SiC particles was reached to a maximum value at 400 mg/l surfactant concentration in the electrolyte. The volume fraction of co-deposited SiC appeared to increase with the surfactant concentration in the electrolyte (Fig. 2a). Co-deposition of SiC increased with increasing surfactant content in the plating

bath. Co-deposition of SiC reached to a maximum value and low concentration of surfactant addition was found inefficient (Fig. 2a).

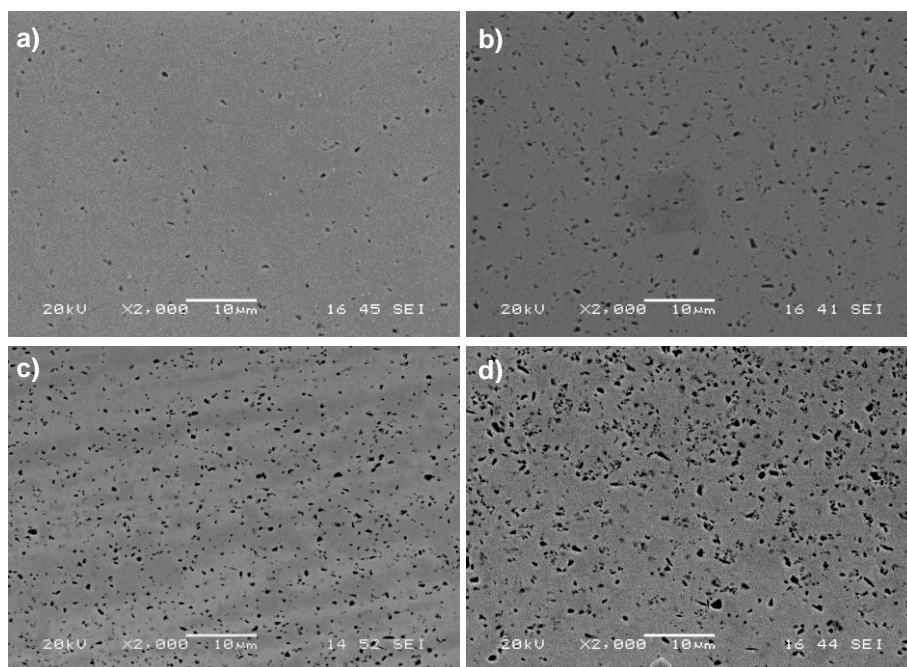


Figure 1. Cross-sectional SEM micrographs of Ni/SiC composite coatings, produced with different CTAB concentrations in the electrolyte; a) 100 mg/l, b) 200 mg/l, c) 300 mg/l and d) 400 mg/l.

The volume fraction of the co-deposited SiC can be increased up to approximately 11 vol. % by increasing the concentration of CTAB in the electrolyte to 400 mg/l. The experimental data shown in Fig. 2a revealed the relationship between the concentration of surfactant (CTAB) in the electrolyte, zeta potential and dispersed SiC particle content in the deposited layer. Increasing zeta potential refers suspending more SiC particles into electrolyte and more co-deposition on the plated substrate [11, 24 and 25]. XRD analysis was used to determine the presence and crystalline phase of SiC nano particles within the matrix of Ni-SiC MMCs. Fig. 2b shows the XRD patterns of pure Ni and Ni-SiC nanocomposites. The intensity of the diffraction peak of (200) nickel in the nano-composite coating is lower, and the peak width is broader than that of the nickel coating as evidenced by many researchers [15, 24]. The Ni-SiC nano-composite has exhibited increasing (111), (222) and (311) diffraction lines with an attenuation of (200) line. This was attributed to the decrease in the grain size of the Ni-SiC nano-composite coating with the addition of SiC nano particles in the plating bath. The nano particles provided more nucleation sites and retarded crystal growth, resulting in a smaller crystal size for the Ni matrix in the composite coating [3]. The reduced crystal size may be correlated with the [100] texture associated with deposits that have minimum hardness and maximum ductility [3, 11, 24].

The effect of particle concentration on hardness of the unreinforced Ni coating and nano-SiC co-deposited Ni-MMCs are measured to increase almost linearly with increasing surfactant content up to 300 g/l surfactant added coating, which yielded 10.05 vol. % SiC with microhardness value of 571 Hv compared to that of hardness of 280 Hv for pure nickel coating. However, increasing particle content to 400 g/l surfactant added coating led to decrease the hardness which is attributed poor interface bonding with increasing surfactant content [3, 15].

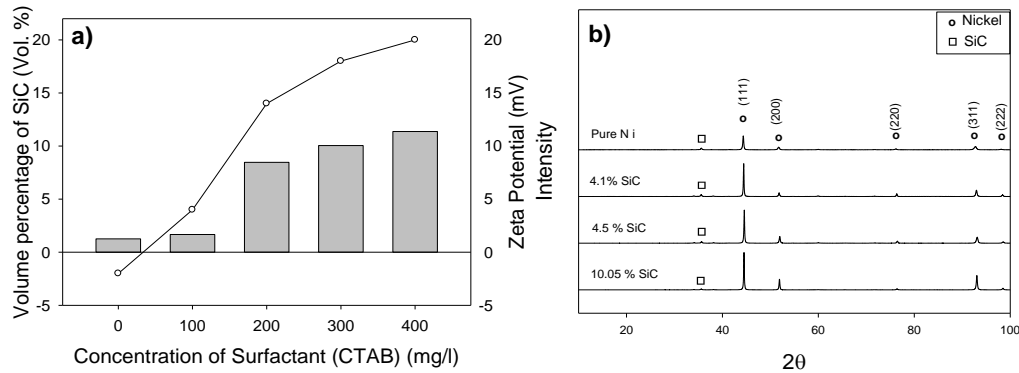


Figure 2. a) Zeta potentials and the volume fraction of SiC particles deposited at various surfactant concentrations in the electrolyte b) the XRD patterns of pure Ni and Ni-SiC nano composites.

3.2. Tribological properties

The reciprocating tribological wear results are presented in Fig. 3. It is observed that the wear rates of composite layers are dependent, mainly on the surfactant concentration in electrolyte and therefore, deposited SiC amount in the coating layer. The maximum volume fraction of SiC (10.05%) exhibited the highest wear resistance. Similar to microhardness data the amount of wear is decreased when the particle content was increased in the deposited layer up to 300 mg/l surfactant charge in the electrolyte corresponding to wear amount decrease of 85 % (Fig 3a) at 100 mm/s sliding speed. In the deposited layer that produced without surfactant addition the wear rate is approximately $22 \times 10^{-4} \text{ mm}^3/\text{Nm}$ whereas, the wear rate decreased to $9,5 \times 10^{-4} \text{ mm}^3/\text{Nm}$ when the surfactant concentration in the electrolyte increased to 300 mg/l for the same sliding speed. This refers shows approximately 2.2 times increase in the wear resistance. Increasing sliding speed resulted in increasing wear rate for the entire composite produced with different surfactant concentrations. The wear rate shows an increasing with increased sliding velocity (Fig. 3a). But the coefficient friction shows a decreasing with increased sliding velocity. When the Fig. 3b is seen the coefficient of friction is decreased almost continuously with increasing sliding speed whereas, surfactant concentration seems to have small effect on the friction coefficient but in a manner that increasing the surfactant content in the electrolyte leads to decrease friction coefficient values.

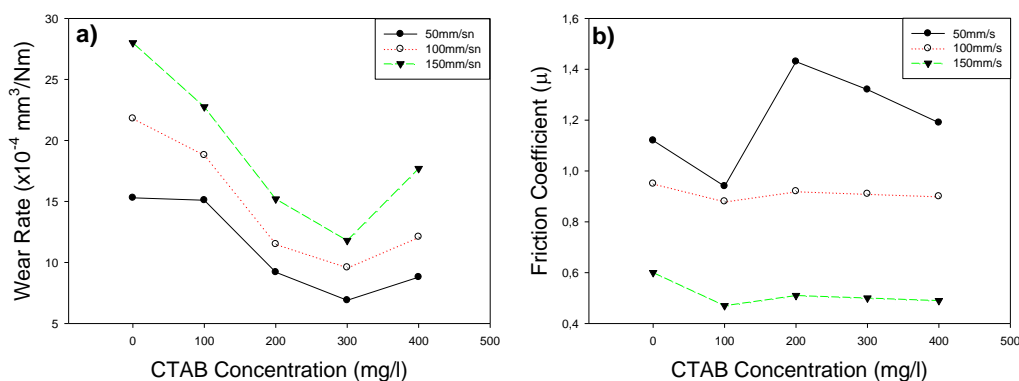


Figure 3. a) Effect of different sliding speeds and surfactant concentration in the electrolyte on (a) wear rate and (b) friction coefficient of Ni/SiC composite coatings.

Fig.4 shows the SEM morphologies of the wear tracks of composite coatings prepared without surfactant addition in the electrolyte at different sliding speeds; a) 50 mm/s b) 100 mm/s c) 150 mm/s. The wear is mainly controlled by microcrack formation after scuffing and galling. It is experienced that increasing sliding speed resulted to obtain smoother worn surface and decreased amount of the microcrack formation.

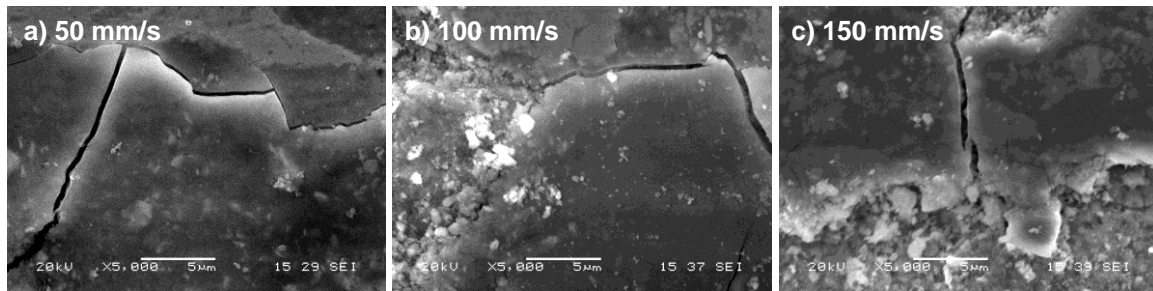


Figure 4. SEM morphologies of the wear tracks of composite coatings prepared with 0 mg/l surfactant concentration at different sliding speeds; a) 50 mm/s b) 100 mm/s c) 150 mm/s.

Fig.5 shows the SEM morphologies of the wear tracks of composite coatings prepared with 100 mg/l surfactant concentration in the electrolyte at different sliding speeds; a) 50 mm/s b) 100 mm/s c) 150 mm/s. The same wear mechanism seen in the surfactant free coatings is also predominant. Increasing sliding speed caused smoother and less microcracks. It is possible to conclude that at the low surfactant concentrations, the worn surfaces showed seizure of the wear debris on the sliding surface and subsequent plastic deformation hardening which was evidenced by microcracks on the surface.

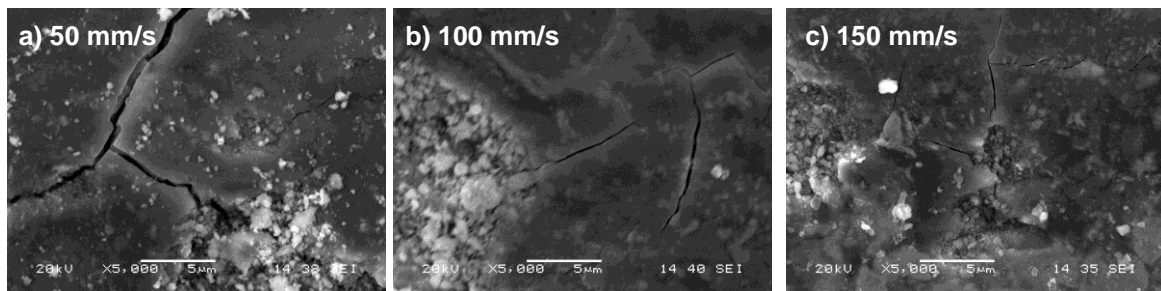


Figure 5. SEM morphologies of the wear tracks of composite coatings prepared with 100 mg/l surfactant concentration at different sliding speeds; a) 50 mm/s b) 100 mm/s c) 150 mm/s.

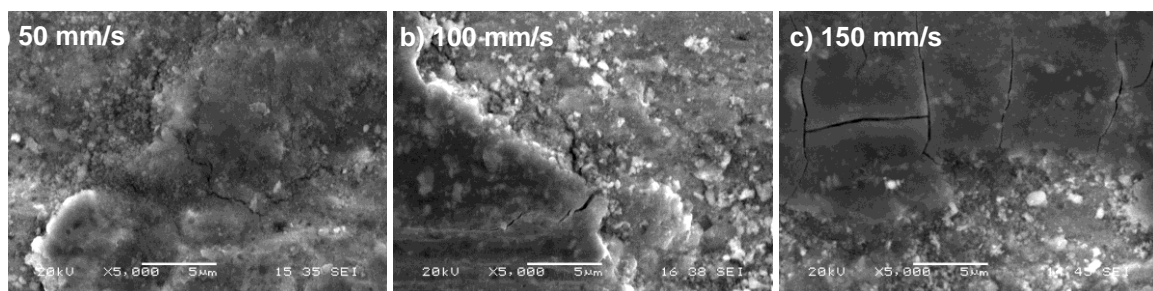


Figure 6. SEM morphologies of the wear tracks of composite coatings prepared with 200 mg/l surfactant concentration at different sliding speeds; a) 50 mm/s b) 100 mm/s c) 150 mm/s.

Fig.6 and 7 shows the SEM morphologies of the wear tracks of composite coatings prepared with 200 mg/l and 300 mg/l surfactant concentrations in the electrolyte at different sliding speeds; a) 50 mm/s b) 100 mm/s c) 150 mm/s. The wear mechanisms are similar for 200 and 300 mg/l surfactant additions. At the 50 and 100 mm/s sliding speed conditions, the worn surface exhibited very fine debris, which composed of a mixture of composite and steel constituents proven by EDS analysis. Increasing sliding speed to 150 mm/s resulted to decrease wear debris but increasing oxygen content, which is an evident that wear mechanism transition to temperature controlled wear. Increasing sliding speed causes more heat generated in the interface and more NiO formation which is known as tribo-oxide for reducing the friction coefficient [26].

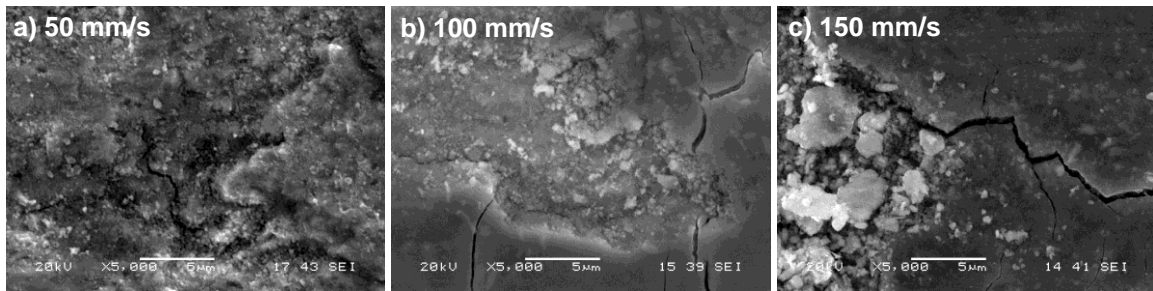


Figure 7. SEM morphologies of the wear tracks of composite coatings prepared with 300 mg/l surfactant concentration at different sliding speeds; a) 50 mm/s b) 100 mm/s c) 150 mm/s.

Fig.8 shows the SEM morphologies of the wear tracks of composite coatings prepared with 400 mg/l surfactant concentration in the electrolyte at different sliding speeds; a) 50 mm/s b) 100 mm/s c) 150 mm/s. The worn surfaces are very rough, and it seems heavy plastic flow occurred. Since increasing surfactant content to 400 mg/l results to decrease interface bonding between matrix and SiC, the wear mechanism shows a mixed mode of adhesive and abrasive wear [3, 15]. Because of the loosely bonded SiC particles galling and seizure on the composite surface of the worn out components subsequently causes three-body abrasion. Increasing sliding speed in this case, resulted also to decrease the surface damage.

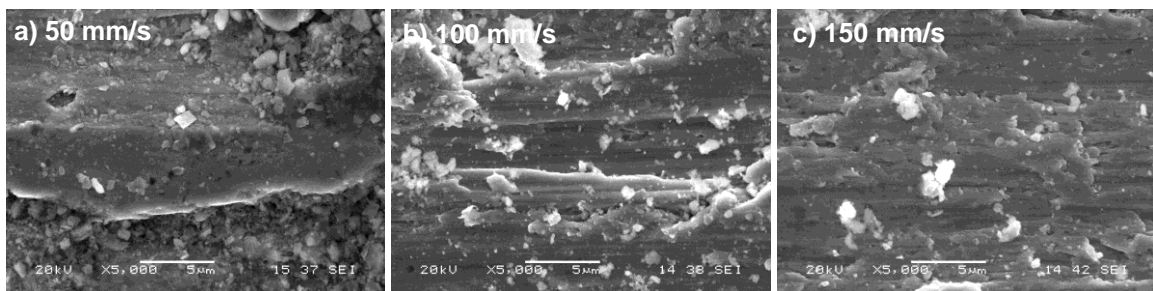


Figure 8. SEM morphologies of the wear tracks of composite coatings prepared with 400 mg/l surfactant concentration at different sliding speeds; a) 50 mm/s b) 100 mm/s c) 150 mm/s.

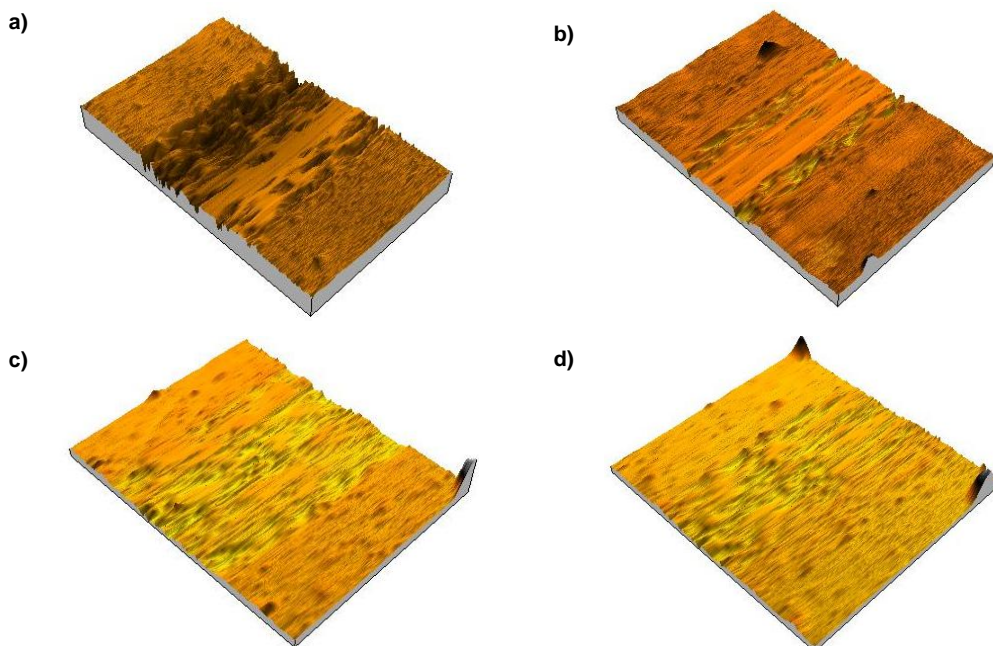


Figure 9. 3D profilometry of the worn surfaces; a) 100 mg/l CTAB-150 mm/s, b) 300mg/l CTAB-50 mm/s, c) 300 mg/l CTAB-100mm/s and d) 300 mg/l CTAB-150mm/s

In Figure 9, some selected worn composite surfaces were presented scanned with 3D profilometry. When the surfactant addition is not enough, it was discussed previously, low amounts of SiC particles were co-deposited in the coated layer, and this causes high amount of wear occurred. In Fig 9a, the composite produced with 100 mg/l CTAB has only 1.67 % SiC in the deposited layer, and the wear rate is high compared with optimum surfactant content 300 mg/l CTAB. Therefore, a large and deep wear track was obtained. Because of the smearing of the debris resulted in formation galling type wear. When the composites were tested with optimum surfactant addition less surface damage was obtained as seen from the Fig 9b,c, and d. As can be seen from the Fig 9, increasing sliding speed produced gradually increase smoothness since formation of NiO caused by temperature increase.

3. Conclusions

1. Nano (100-1000 nm) SiC particle reinforced Ni MMCs were successfully produced by D.C. electroplating up to 10.05 vol. % particle co-deposition.
2. Increasing the surfactant content in the electrolyte up to 400 mg/l resulted in increasing particle volume. However, beyond 300 mg/l surfactant hardness and tribological properties started to become worse because of poor interface bonding between Ni and SiC.
3. Increasing surfactant content in the co-deposited Ni–SiC nano-composite coatings yielded decreasing wear rate up to 300 mg/l surfactant (CTAB) addition. However, no significant change was observed in the friction coefficient values.
4. Increasing sliding speed resulted in a gradual increase in the wear rate but again, a gradual decrease in the friction coefficient.
5. Increasing surfactant content showed decreasing the surface damage in the composite worn surfaces up to 300 mg/l. The predominant wear mechanism was observed to be galling and scuffing combined with surface hardening and then microcrack formation.
6. Increasing sliding speed resulted in transition from adhesive to oxidative wear mechanisms because of increasing surface temperature and tribo-oxide formation.

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