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Research Paper

Fabricating the Tribological Properties and Investigating of Ni_3Al-MoS_2 Composite Coating

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ABSTRACT

Self-lubricant coatings are among the newly improved type of coatings to reduce the coefficient of friction and protect the substrate in various conditions. Magnetron sputtering is the best technology to fabricate coatings with good morphology. In this paper, the tribological properties of magnetron sputtered Ni_3Al-MoS_2 coating on 4340 steel are reported. For this purpose, five tablets of Ni_3Al-30 wt.% MoS_2 were prepared as the target material and were placed in a copper holder. At last, we have sputtered from the target using the best sputtering condition to get a good morphology and microstructure of the coating. The morphology and microstructure of the coatings were characterized by X-ray diffraction (XRD) and scanning electron microscopy (SEM). The tribological properties of Ni_3Al-MoS_2 coating were investigated using a ball-on-disc tribometer at atmospheric conditions at room temperature. SEM was used to examine the morphology of the wear track after the ball-on-disc test. The Ni_3Al-MoS_2 composite coating showed lower frictions coefficient and higher wear resistance because of the hard Ni_3Al matrix and soft MoS2 particles.

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1. Introduction:

Metal matrix composites with solid lubricants have attracted wide and promising applications [1-7]. Aluminides have served interesting properties such as high hardness, high-temperature stability, high creep resistance, high melting point and, low density [8,9]. A Combination of aluminides with solid lubricants particles has been considered as self-lubricating materials [10-16]. Solid lubricants have been classified into several subdivisions, such as lamellar solids (e. g., MoS_2, WS_2 and, graphite), soft metals (e. g., Ag and Pb), carbon-based solids (e. g., diamond and DLC), and organic materials/polymers (e. g., PTFE and waxes) [10-17]. MoS_2 has a lamellar structure, the bonding in the S-Mo-S sandwich is covalent and strong, but the layers of the lamellar structure are van der Waals and weak. It yields a low friction coefficient value and is mostly used in applications that need a solid lubricant [15-17]. The friction coefficient increases and the lifetime decreases when MoS_2 is used in humid air, therefore; this material can be only used in vacuum and in a water vapor-free environment [15-21]. In a previous study, composite coating of Cu-Ni3Al-MoS2 made using the PVD method and a complex target showed a coefficient of friction of about 0.5 after 60 minutes [16]. In this design, it is predicted that by removing copper, the coating will have a higher hardness and its tribological properties will be improved, So this study aimed to synthesize Ni_3Al-MoS_2 coating by magnetron sputtering, and The tribological behavior of the coating was evaluated.

2. Experimental

2.1. Deposition

The Ni_3Al powder was synthesized by ball milling of elemental Ni (80-100µm, 99.9% purity) and Al (80-100µm, 99.9% purity) using planetary ball mill for 40 hours at a speed of 350rpm at room temperature under Ar atmosphere. The MA product was characterized by X-ray diffraction (Bruker X'PERT MPD diffractometer) using filtered Co Kα radiation (λ=0.1789A°), Ni_3Al-30wt.%MoS_2 composite tablets (30mm in diameter and thickness of 2mm) were made by single-axis Santam press under 350 MPa stress. Finally, five tabs were placed in a pure Cu holder which was covered by aluminum foil to prevent the copper element from penetrating into the coating. Depending on the coating conditions and the type of process used, the alumina formed on the foil acts as an insulator and the possibility of its penetration into the coating is reduced [22]. Ni_3Al-MoS_2 coating was deposited by DC magnetron sputtering on 4340 steel substrates. Fig.1 is a schematic diagram of the magnetron sputtering process with Ni_3Al-MoS_2 target tablets. Table 1 shows the coating deposition conditions.

Table 1 Shows the coating deposition parameters.

Target	Ni_3Al-MoS_2
Substrate	4340
Substrate temperature	325°C
Substrate to target distance	15Cm
Voltage	850V
Current	1.2-2A
Deposition time	80min
Base pressure	10^{-7}mbar
Working pressure	1-5×10^{-3}mbar

The composite coatings with a thickness of 8µm were obtained by sputtering for 80 min. The Ni_3Al-MoS_2 coatings were examined by both X-ray diffraction (Philips X'PERT MPD CuK_α) and scanning electron microscopy (SEM Leo 440i OXFORD).

2.2 Testing:

2.2.1. Tribological properties measurements

The tribological properties of 4340 steel substrate and composite coatings were studied by a ball-on-disc tribometer. Table 2 shows the initial conditions of the samples.

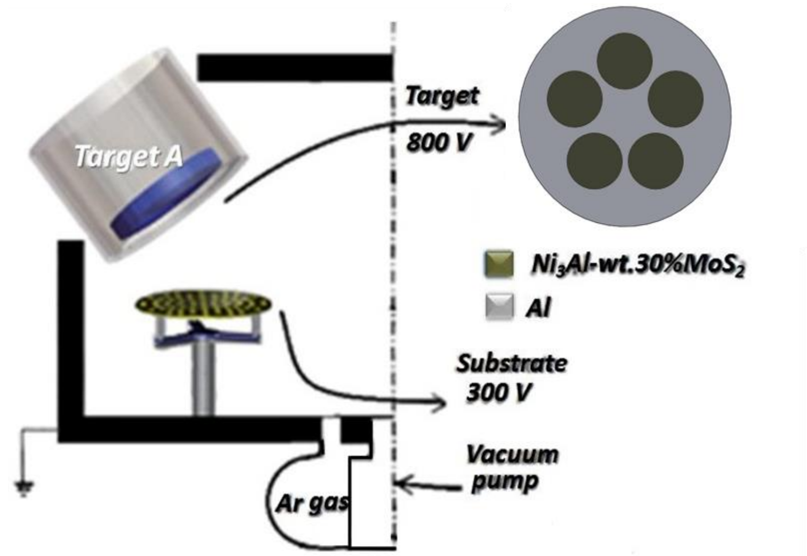


Fig.1. Schematic diagram of sputtering system for synthesizing Ni_3Al-MoS_2 composite coating.

Table 2 Different samples

Samples	Type	Hardness	Roughness (μm)
1	4340 steel	50HRC	R_a= 0/2
2	4340 steel with Ni_3Al-MoS_2 coating	408HV	R_a= 0/08

All tests were carried out using a 5 mm diameter Si_3N_4 ball as the counterface. The tests were run under a load of 5 N at room temperature and a sliding speed of 0.1 m/s. The sliding load in the tribological test was monitored and recorded for 3600 seconds in order to determine the friction coefficient vs. time. The wear tracks of the coatings were examined by means of SEM.

2.2.2. Hardness measurement:

The hardness of the substrate was determined using a Rockwell C hardness with a Koopa attachment. The hardness measurements of the coatings were conducted according to ASTM 578-87 standard, using Wilson microhardness with Vickers diamond pyramid indenter under 25gr force in several points.

2.2.3. Roughness survey:

To determine the roughness of the substrate and coating surfaces was determined by a Mahr Germany device (M300C model).

2.2.4. Adhesion strength

The VDI 3198 standard specifies the well-known Rockwell C indentation test as a destructive quality test for coated compounds [23]. This technique does not give any absolute measurement of adhesion, but comparative results can be obtained with the same load for all samples. Fig. 2 gives qualitative adhesion properties considering the crack network from the indentation spot. This test also gives a qualitative measure of the toughness of the coating. The reported adhesion value ranges between HF1 to HF6 (HF is the German short form of adhesion strength) (Fig.2), with excellent adhesion property and a few crack networks in HF1 and the poorest adhesion properties indicating complete delamination of the coating in HF6 [24,25]

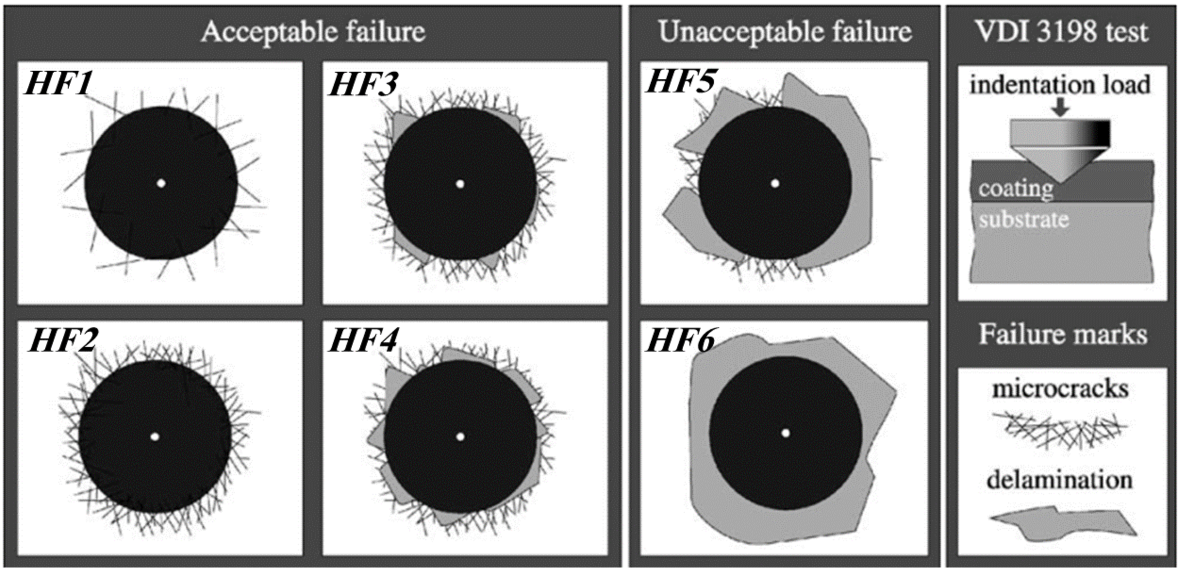


Fig.2. Adhesion strength quality based on Rockwell C indention test [24].

3. Results and discussion

Fig. 3 indicates that the coating has a good flat surface. The observed bumps are a result of MoS_2 dots. A typical SEM image obtained from the surface and the elemental map of the Ni_3Al-MoS_2 composite coatings are shown in Fig.4. The chemical compositions which are determined by energy dispersive spectroscopy (EDS) on SEM are given in table 3. Fig.5 shows backscatter electron (BSE) micrographs. The dark areas in the BSE image are MoS_2 because MoS_2 has a lower atomic mass. The Ni_3Al-MoS_2 composite coatings exhibit a dense structure. The thickness of the coating at the highest target current of 2A was 8µm. The measured microhardness of this coating was 408 HV.

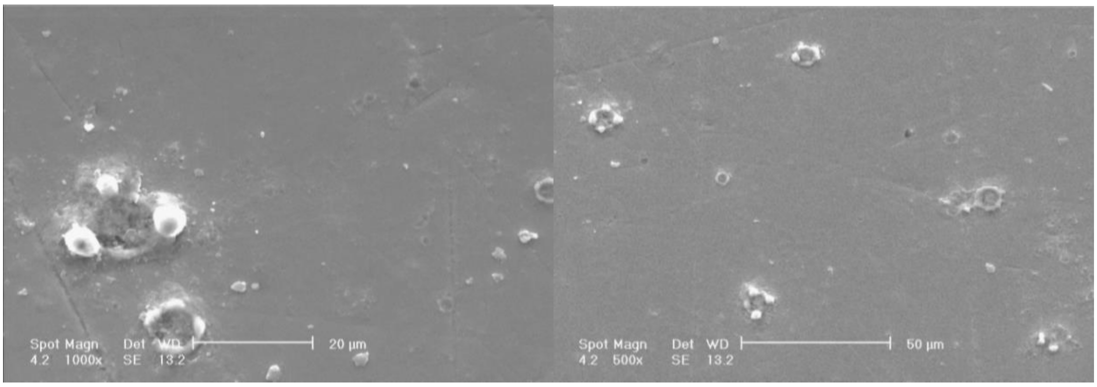


Fig.3. SEM images showing the surface of the Ni_3Al-MoS_2 composite coating.

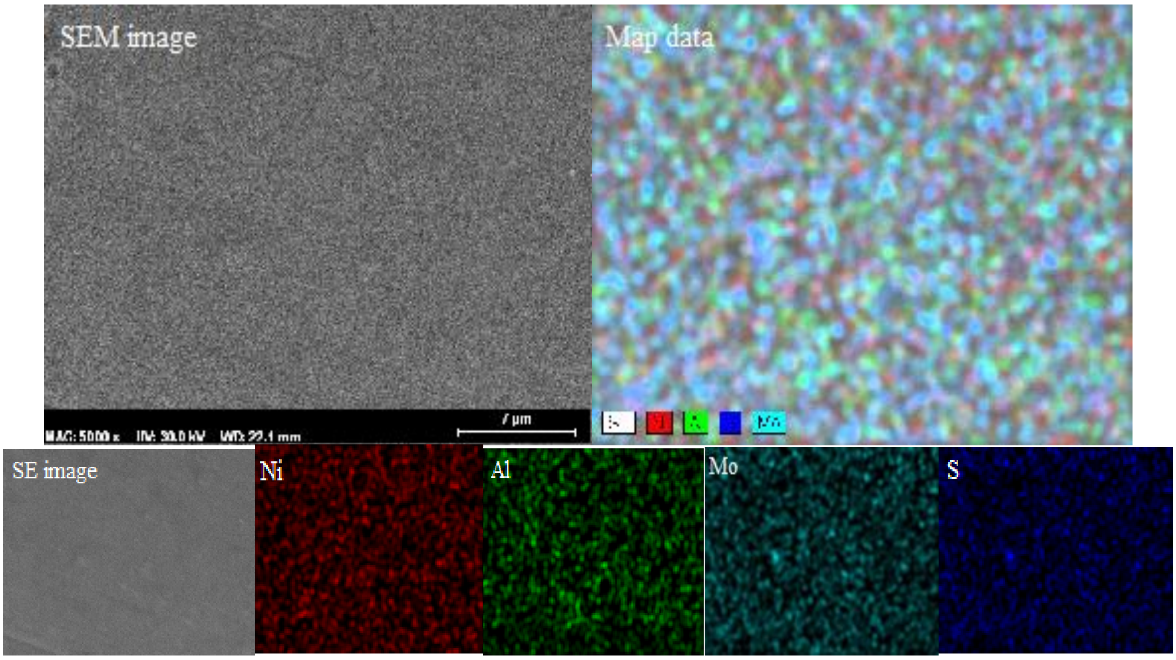


Fig. 4. SEM images showing the elemental map data of the Ni_3Al-MoS_2 composite coating.

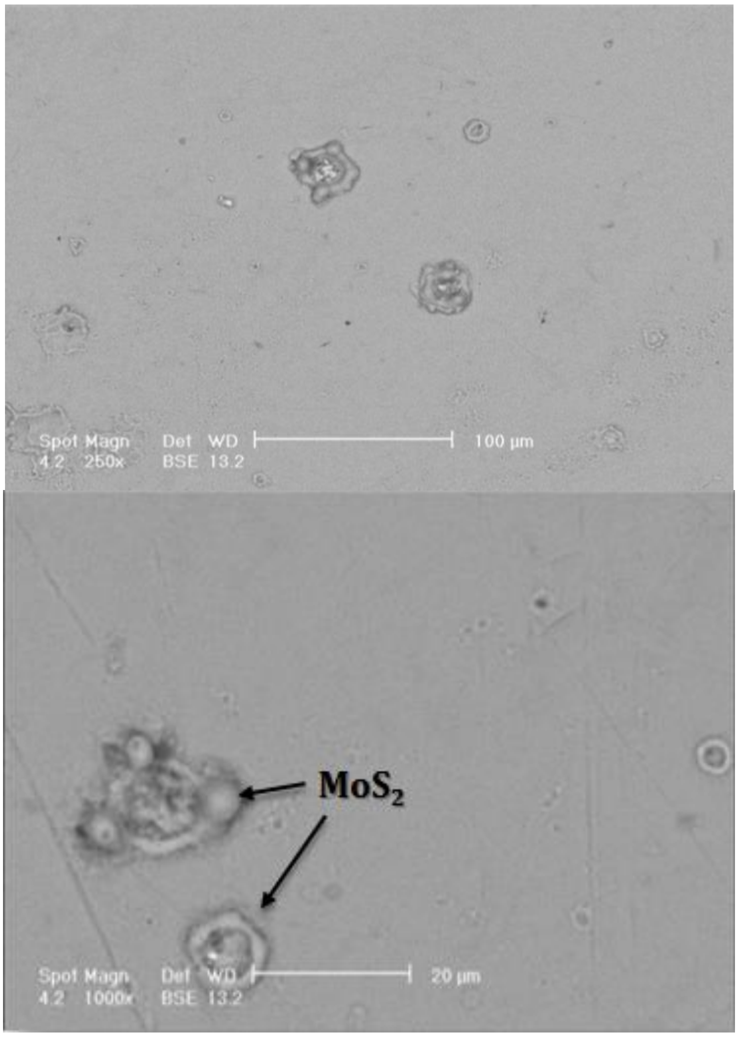
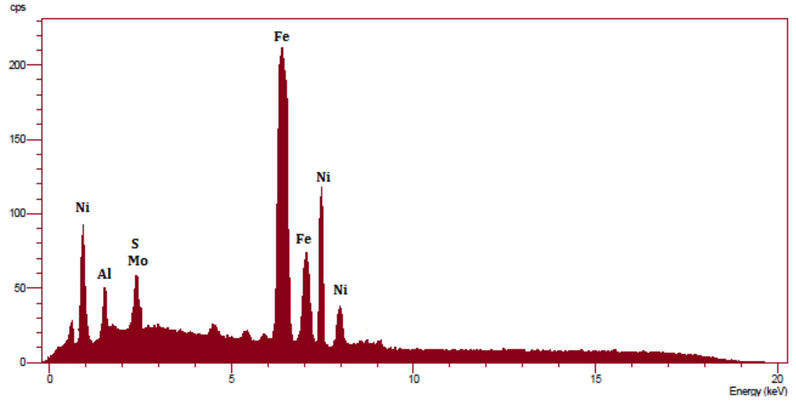


Fig. 5. BSE image of the Ni_3Al-MoS_2 composite coating.

Table 3 The chemical composition measured by EDS



Element	Ni%	Al%	Mo%	S%
Atomic percent	70	25	2	3

3.1. XRD analyses

The X-ray diffraction pattern of Ni_3Al-MoS_2 composite coating is shown in Fig.6. The X-ray diffraction profile revealed that the coatings were mainly consisted of Ni_3Al and MoS_2 phases, with no preferred orientation. Diffraction peaks of AlNi can be observed besides Ni_3Al. One definition can be the Al foil, which has covered the target surface.

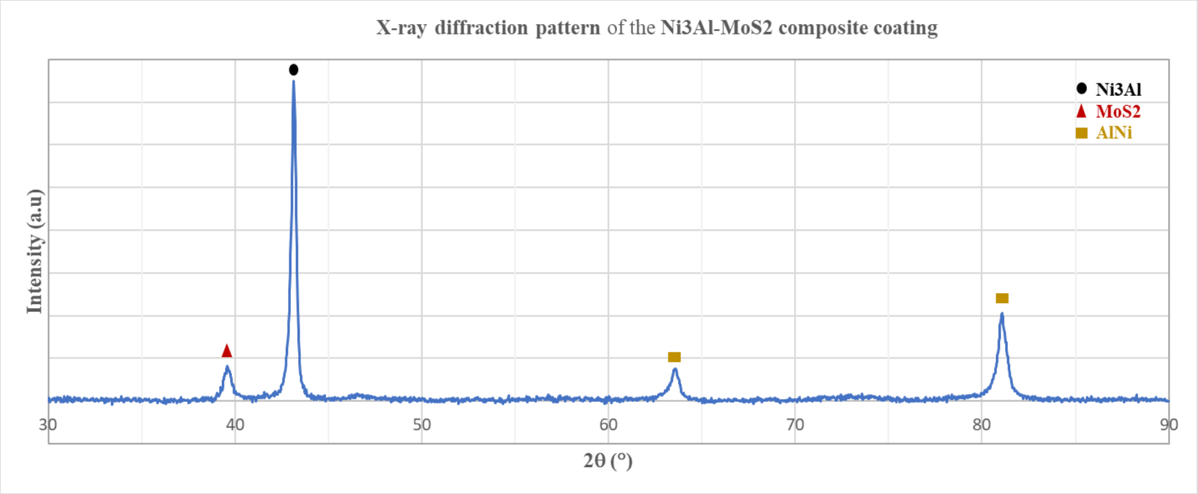


Fig. 6. XRD pattern of Ni_3Al-MoS_2 Composite Coating.

3.2. Adhesion strength

Fig.7 shows the optical micrographs of Rockwell-C indention on Ni_3Al-MoS_2 coating. The Rockwell-C indention test showed an acceptable adhesion. According to the standards presented in the previous section [23-25], coating adhesion strength was evaluated to be HF3, which represents good adhesion and strength to the substrate.

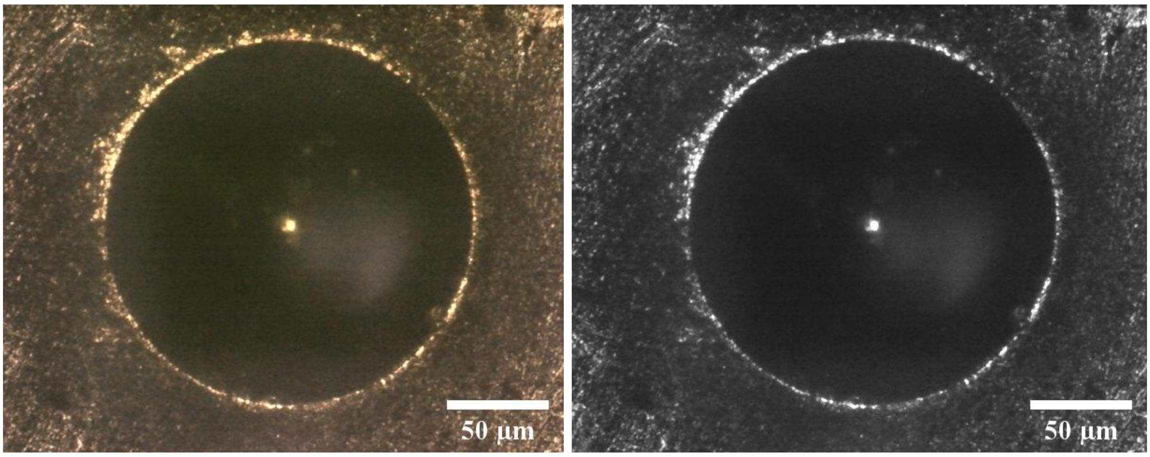


Fig. 7. Rockwell C adhesion test of Ni_3Al-MoS_2 coating (load 150kg).

3.3. Tribological properties measurements

Fig.8 (a) illustrates the evolution of the friction coefficient of the composite coating under dry sliding for the duration of 1 h at a sliding speed 0.1 m/s and an applied load of 5 N. The friction coefficients of the coating were approximately 0.2 in 25 ºC. In comparison, the friction coefficients of the 4340-steel substrate were much higher (above 0.9) than that of the coating. These results prove that the Ni_3Al-MoS_2 coating exhibits excellent self-lubricating properties. Fig.8 (b) shows the mass loss results. The mass losses of substrate and coating were 0.02 and 0.005 gr, respectively. Humidity has a positive effect on friction coefficient, and decreases wear life which is probably because of dangling unsaturated bonds on the edge of basal plans reacting with moisture and oxygen in the environment to form triboxidation products, such as MoO_3 [26-28].

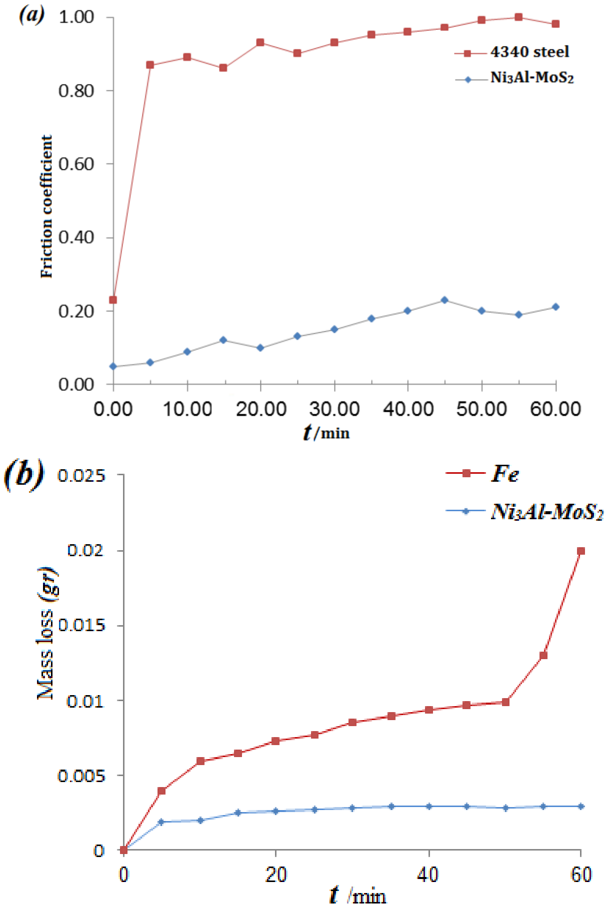


Fig. 8. (a)The friction coefficients and (b) mass loss of the coating at room temperature

Fig. 9 (a) shows the worn surfaces of the coating after wearing for 1 h at a load of 5 N and sliding speed of 0.1 m/s at room temperatures. The parallel furrows and spallation are observed, which reveal that the wear mechanism is abrasive. Fig. 9(b) given the EDS data taken from the wear area. EDS analysis was performed to determine the surface composition in the wear track. EDS confirmed the presence of Ni, Al, Mo and, S within the composite coating (Table 4). The worn area on the film counter body is smooth with patchy and powdery debris. Some worn debris piled up at both sides of the wear track with no abrasive wear effect. This is the reason why the friction coefficient remained very stable during the 1 h sliding test. The overall aspects of this worn surface image are typical for all coating studied here. The wear resistance of coatings depends on several factors, including the hardness, thickness, plastic deformation behavior, roughness and, lubricating properties. By properly adjusting these parameters, the wear behavior can be improved [29]. The microhardness test on the coating indicates that the coating hardness was 408 HV; due to the lower hardness of coating in comparison with the substrate, the coating half-life is low. However, the amount of lubricant material MoS2 provides the condition for improving the lubrication.

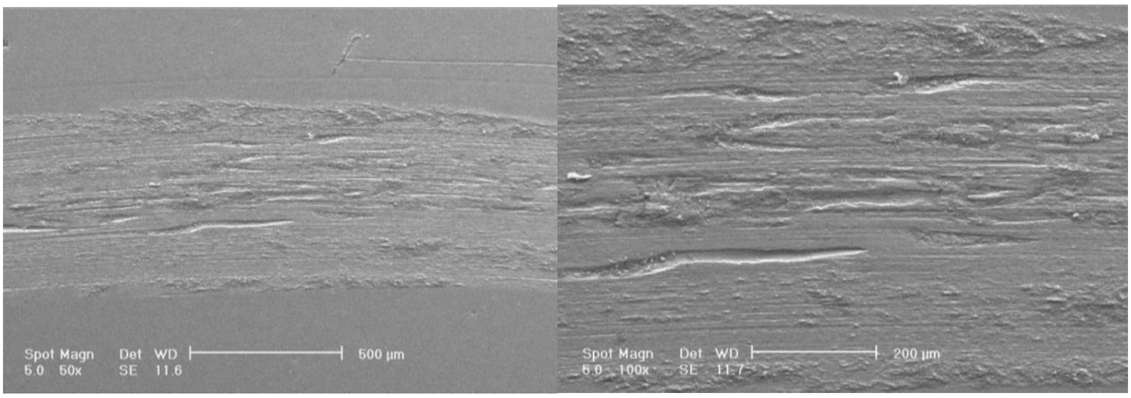
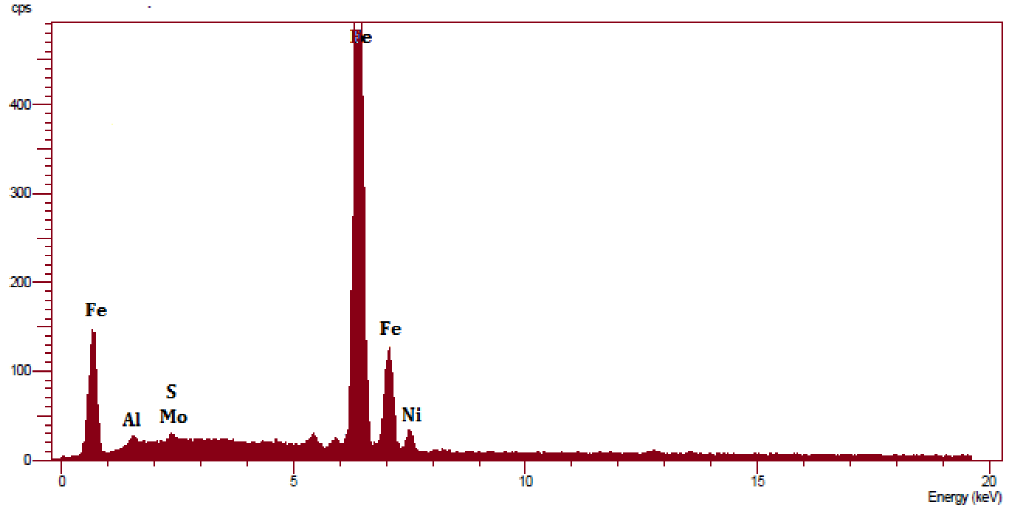


Fig. 9. SEM micrographs of worn surface of the coating (0.1 m/s, 5 N and 1 h).

Table 4 EDS of wear area



Element	Ni%	Al%	Mo%	S%
Atomic percent	12	6	0/5	1/5

3.4. Investigation wear rate of the coating and substrate

Fig. 10 shows the wear rate of the as-received substrate and Ni_3Al-MoS_2 coating. The presence of the soft MoS_2 particles within the hard Ni3Al matrix and the smoothness of the surface, and the good adhesion strength of the coating to the substrate all contribute to the improvement of the substrate tribological properties reduces the wear rates. The wear rate of the coating was 50% smaller than that for the substrate.

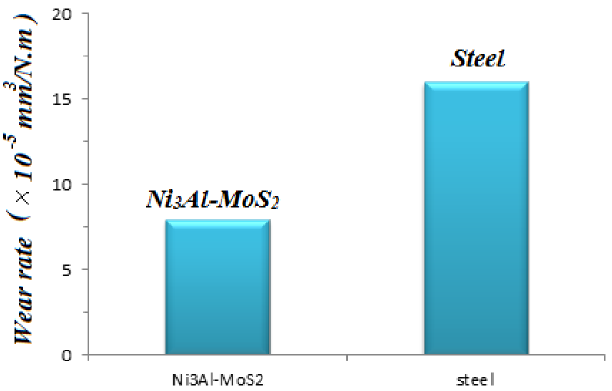


Fig.10. Wear rate of coating and substrate

4. Conclusions

XRD analysis indicated that the composite coating had no preferred orientation. In the BSE image, the dark area is the MoS_2 phase observed. The first coefficient of friction at room temperature is 0.24. These results prove that the coating provides a stable and low friction coefficient in stable conditions; in other words, it proves the coating exhibits self-lubricating properties. The main reason for the low coefficient of friction seems to be the presence of a composite structure containing hard matrix Ni_3Al with solid lubricant MoS_2. In addition, no failure(s) were observed during the wear test.

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