The Tribological Properties of Cu-Ni_3Al-Mos_2 Composite Coating Deposited by Magnetron Sputtering

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ABSTRACT

In industrial applications, most materials are exposed to wear and friction because multiple conditions are used. However, the tribological properties of these materials can be improved with different techniques. One such technique that improves the frictional property of a surface is the use of self-lubricating coatings. In this study, multicomponent coatings of nominal composition Cu-Ni_3Al-MoS_2 have been sputter from the target using the best sputtering condition to get a good morphology and microstructure of the coating. The morphology and micro structure of the coatings were characterized by X-ray diffraction (XRD), scanning electron microscopy (SEM) and energy depressive spectroscopy (EDS). The measured microhardness of this coating was 380 HV under a load of 25 g. Tribological properties of Cu-Ni_3Al-MoS_2 coatings were investigated using ball-on-disk (BOD) tribometer at room temperature. These composite coatings showed a good morphology and adhesion of the coating to the substrate. Also, it had acceptable friction coefficient and higher wear resistance due to its hard matrix containing Cu-Ni_3Al and MoS_2 Nano particles.

1. Introduction

Cu-matrix composite coatings have a high hardness, friction coefficient; wear resistance, thermal and electrical conductivity for several engineering applications. Metal-matrix composites can be improved by the incorporation of reinforcing elements to develop wear resistance and structural applications [1, 2]. In Cu-Ni_3Al-MoS_2 composite coating, Ni_3Al is used to reinforce and increase wear resistance, because it has a good physical/mechanical properties, melting point, thermal conductivity, and strength [3, 4].

A very large variety of self-lubricating coatings have been developed, includeing soft metal coatings [5], transition metal dichalcogenide coatings [6], carbon based coating [7], oxide [8], fluoride [9] and sulfate [10] coatings, and polymer coatings [11].

MoS_2 particles help to improve the rolling and sliding properties of tribocomponents encountered in micro/nano electromechanical systems [1, 2]. It has a lamellar structure. The bonding among atoms is covalent and strong, but the layers of the structure are quite weak. The low friction occurs because of the lamellar structure and weak Van der Waals bonding of MoS_2 [12, 13]. To benefit from the friction properties, the layers of MoS_2 have to be parallel to the substrate surface [12]. The friction coefficient increases and the lifetime decreases when MoS_2 is used in humid air; therefore, this

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material is only used in vacuum and in water vapor-free environments [14].

In recent years, the attainment of composite coatings has become relatively easy using physical vapor deposition and CVD technologies [15-17]. These coating deposition techniques offer a wide variety of means and flexibility for depositing solid lubricant or self-lubricating coatings on substrates of various shapes and materials [18]. In this study, Cu-Ni_3Al-MoS_2 composite coatings were deposited onto 4340 steel using the magnetron sputter system. Pin-on-disk friction experiments were conducted by Si_3N_4 balls in sliding contact with the composite coating at room temperature. The composite coating and their wear surface were examined by SEM and EDS. These techniques were used to determine the structural morphology and elemental composition of the worn surface and some wear debris.

2. Materials and methods

2.1. Deposition

Cu-Ni_3Al-MoS_2 coating was deposited by Dc magnetron sputtering on 4340 steel substrates. Generally, the resulting coating properties are highly dependent on the preparation parameters due to the non equilibrium nature of the sputter-deposition process. The main process parameters are: the substrate temperature, the substrate bias voltage, the sputters gas pressure, the deposition rate and back ground pressure [3]. Deposition parameters are given in Table 1.

The magnetrons within the coating chamber were arranged so that one pure Cu target containing 6 tablets of Ni_3Al-30%MoS_2 was used. Figure 1 presents a schematic picture of Cu-Ni_3Al-30%MoS_2 target designed and Figure 2 displays a schematic diagram of the magnetron sputtering process with Cu-Ni_3Al-MoS_2 target. Ni_3Al-30%MoS_2 tablets were fabricated by press milling the mixture of pure Ni_3Al and MoS_2 powder, followed by pressing the mixture under the pressure of 350 Mpa. Afterwards, the composite coatings with a thickness of 4 μm were obtained by sputtering the composite targets.

2.2. Chemical composition analysis

The phases of Cu-Ni_3Al-MoS_2 coatings were characterized by X-ray diffraction (XRD, Philips X'PERT MPD) with Cu-Kα radiation (λ=1.54056A°) and the scan step size was 0.05°.

2.3. Micro structure examination

The morphology of composite coatings was observed by means of LEO-440i Oxford scanning electron microscopy (SEM) at an acceleration voltage of 20 kV.

2.4. Mechanical and tribological properties measurements

Micro hardness of the coating was measured by using the WILSON tester. A load weight of 25 gr was applied to perform the indentation and maintained for 10 S. The tribological properties of the coating were characterized on a ball-on-disk at room temperature tribometer and tested at the sliding speed of 0.10 m/s, under a load of 5 N and duration of 1 h. The wear and friction tests were conducted at room temperature. The counterpart ball was the Si_3N_4 with a diameter of 5mm.

2.5. Adhesion strength

This technique does not give any absolute measurement of adhesion but with the same load for all samples comparative results can be obtained. Figure 3 gives a qualitative adhesion property considering the crack network from the indentation spot. This test also gives a qualitative measure of the toughness of the coating. The adhesion value is reported from HF1 to HF6 (HF is the German short form of adhesion strength) (Figure 3). HF1 shows excellent adhesion property with a few crack networks while HF6 shows the poorest adhesion properties showing complete delamination of the coating [19].

3. Results and discussion

3.1. Chemical composition analysis

The XRD pattern of the Cu-Ni_3Al-MoS_2 coating is presented in Figure 4, where two diffraction peaks can be found. The diffraction peaks are in accordance with the standard diffraction peak of Ni_3Al and Cu (111), (002). The diffraction pattern of the coating did not show any evidence of MoS_2, but the EDS results indicated the presence of this material in the coating. Figure 5 shows the EDS analysis: the Cu and Ni_3Al and MoS_2 phases have an approximately uniform distribution in the coating. The important point

Table 1. Sputtering parameters and details of the coating deposition

Substrate	target	Substrate to target distance	Applied voltage to substrate	Applied current to target	Applied current to substrate	Deposition time	Base pressure	Working pressure
4340 steel	Cu-NiAl-MoS_2	15 cm	300 V	1.2-2 A	0.5 A	27 min	10^{-7} mbar	5×10^{-3} mbar

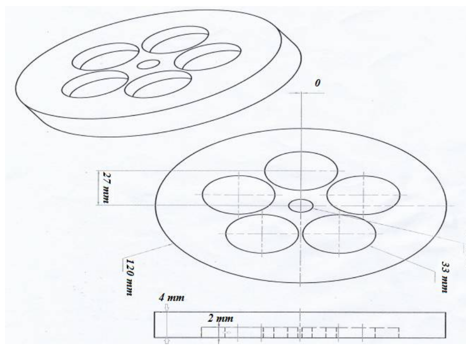


Fig. 1. Schematic picture of Cu-Ni_3Al-30%MoS_2 designed target.

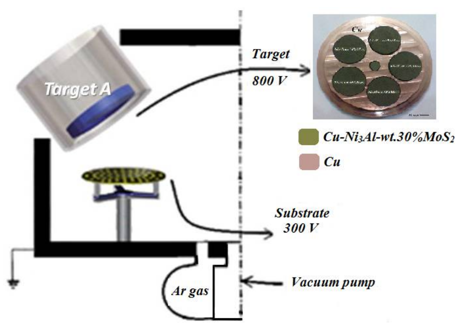


Fig. 2. Schematic diagram of the magnetron sputtering process.

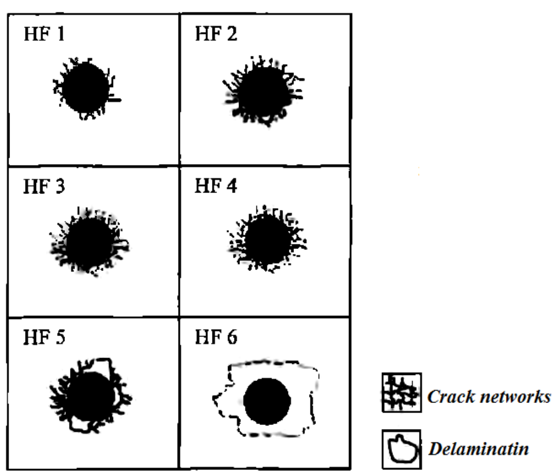


Fig. 3. Adhesion strength quality based on Rockwell C indention test [19]

growth in all crystalline directions, diffraction fails to occur in all crystalline pages or may have low intensity. So, they do not show a crystal X-ray diffraction from all pages. Figure 6 is a schematic illustration of the formation and growth of Fe-Mn oriented to the (111) plane [20].

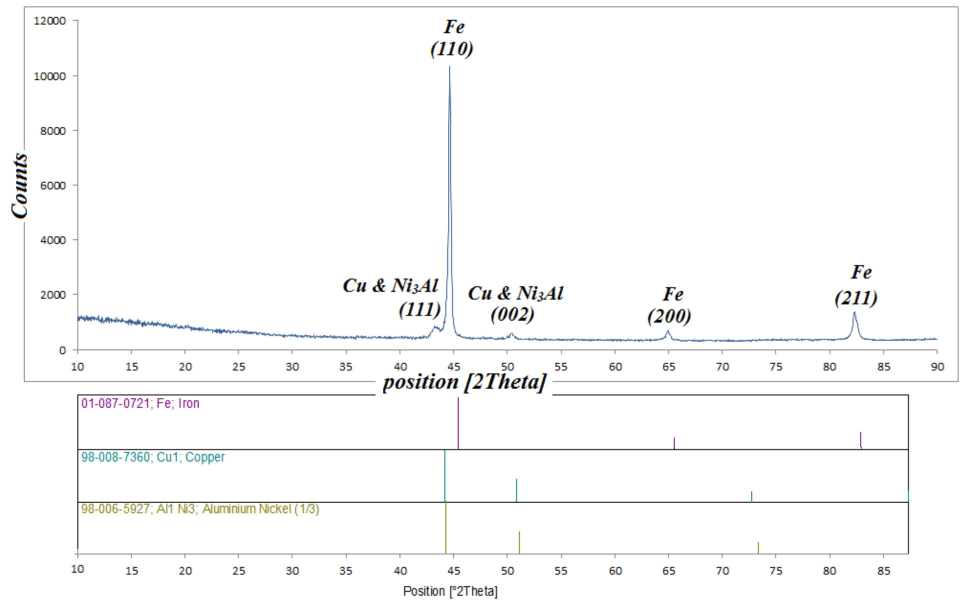
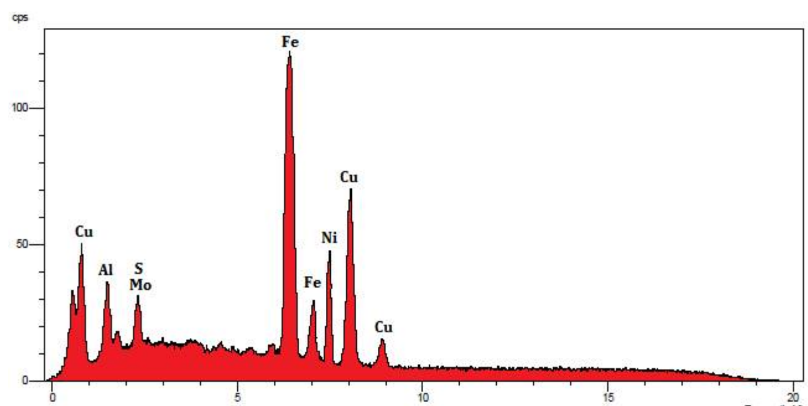


Fig.4. XRD pattern of Cu-Ni_3Al-MoS_2



Elements	Cu	Ni	Al	Mo	S
%at	77	15	5	1	2

Fig. 5. About quantitative values of Cu-Ni_3Al-MoS_2

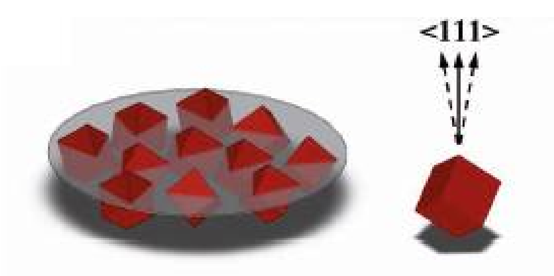


Fig. 6. Schematic illustration of in the structure covering the physical vapor deposition method [20]

3.2. Adhesion strength

Figure 7 shows the optical micrographs of Rockwell-C indention on the Cu-Ni_3Al-MoS_2 coating. The Rockwell-C indention test shows an acceptable adhesion. According to the standards presented in the previous section, the coating adhesion strength was evaluated to be HF1, which represents good strength of adhesion to the substrate. Few crack networks were observed around the indention spot, as displayed in figure 7.

3.3. Microstructure and microhardness of the composite coatings

The cross-section of the as-deposited coating on glass is shown in Figure 8. The thickness of the coating at the highest target current of 2A was 4μm. The measured microhardness of this coating was 320HV. The morphology of the Cu-Ni_3Al-MoS_2 composite coatings illustrated in Figure 9 indicates that the coating has a good flatness and dense surface.

3.4. Tribological properties of the composite coating

Figure 10 illustrates the evolution of the friction coefficient of the composite coating under dry sliding for the duration of 1 h. The friction coefficient changes as a function of the sliding time. The friction force was continuously monitored during the friction experiments. The sliding wears life for the coating in this investigation was determined in terms of the number of passes at which the initial coefficient of friction was between 0.4-0.5 at the end of 600 S sliding times. As the sliding time increases to 3600 S, the friction coefficient remains a low, constant value (μ: 0.5) maintained until the end of the test (Figure 10). A thin and uniform transfer film on the Si_3N ball is observed at the test conditions. Figure 11 shows the contacting area on the ball.

As can be seen in Figure 12, the EDS data were taken from two positions in the wear track where the worn surface from the composite indicates two worn zones. The EDS analysis was performed to determine the surface composition in each of the two zones. A qualitative analysis by EDS confirmed the presence of Cu, Ni, Al, Mo and S within the composite coating (see Figure 5). 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. In the frictional process, the coating was crushed and adhered to the substrate, preventing the direct contact between the 4340 steel and Si_3N ball. Therefore, its friction-reduction property is very good. This is the reason why the friction coefficient remained very stable during 1 h sliding test. The overall aspects of this worn surface image are typical of all the multicomponent systems that have been studied. It is well known that the main reason for low coefficient of friction seems to be pressure

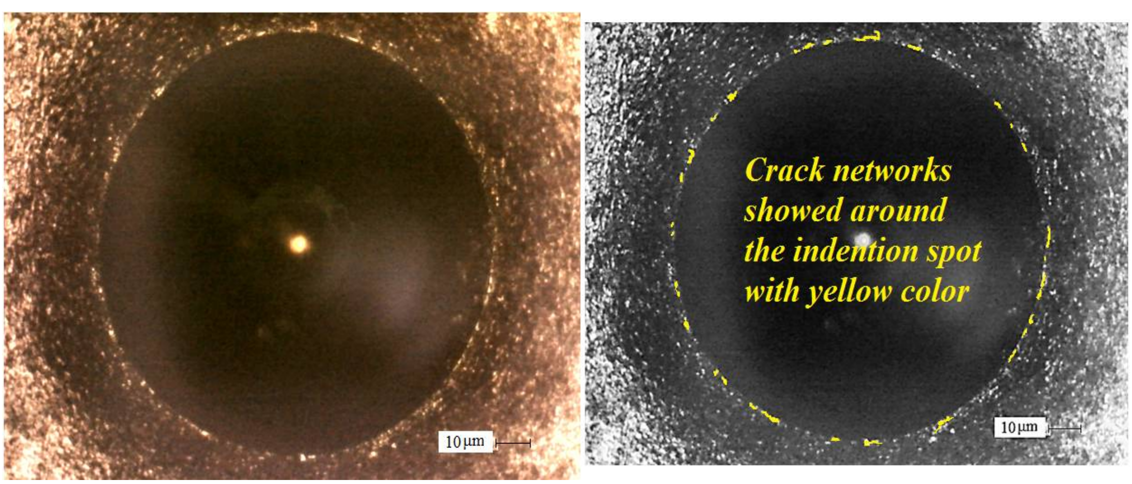


Fig.7. Rockwell C adhesion test of Cu-Ni_3Al-MoS_2 coating.

composite structure of Cu-Ni_3Al with MoS_2 composite in the coating.

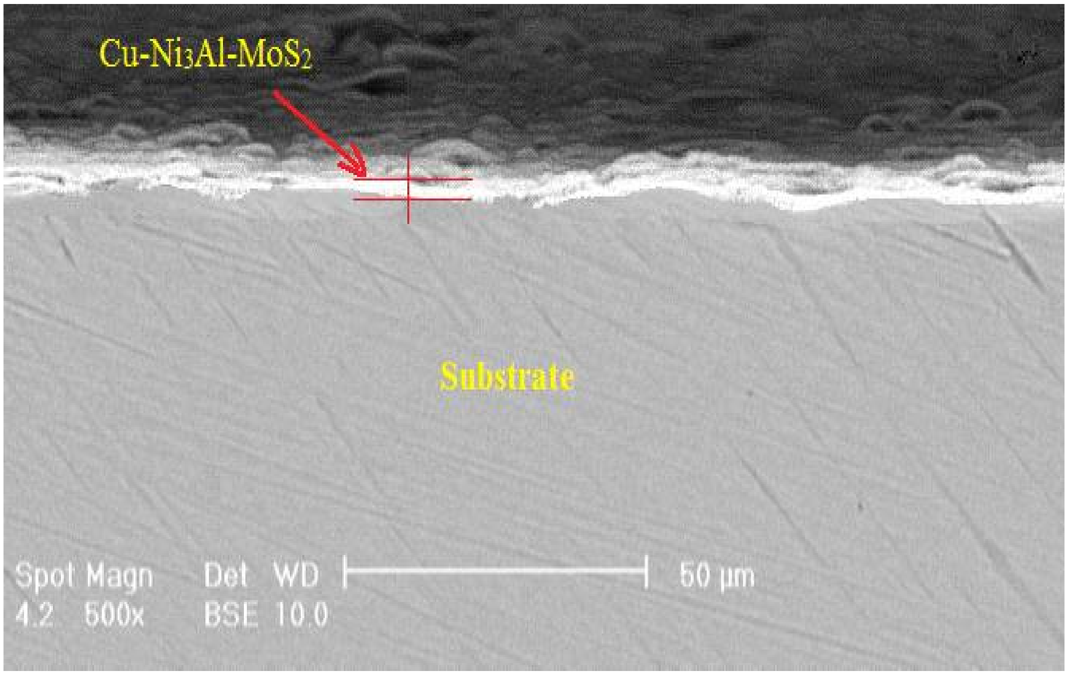


Fig. 8. Cross section of the sample

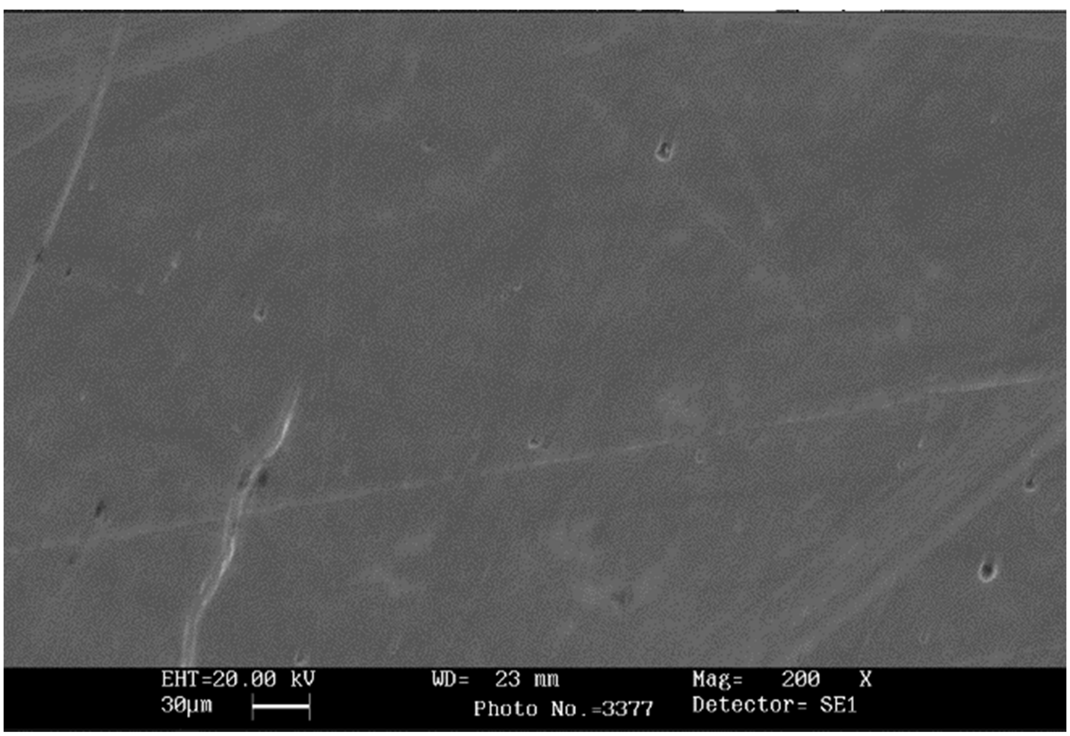


Fig. 9. SEM image of the coating.

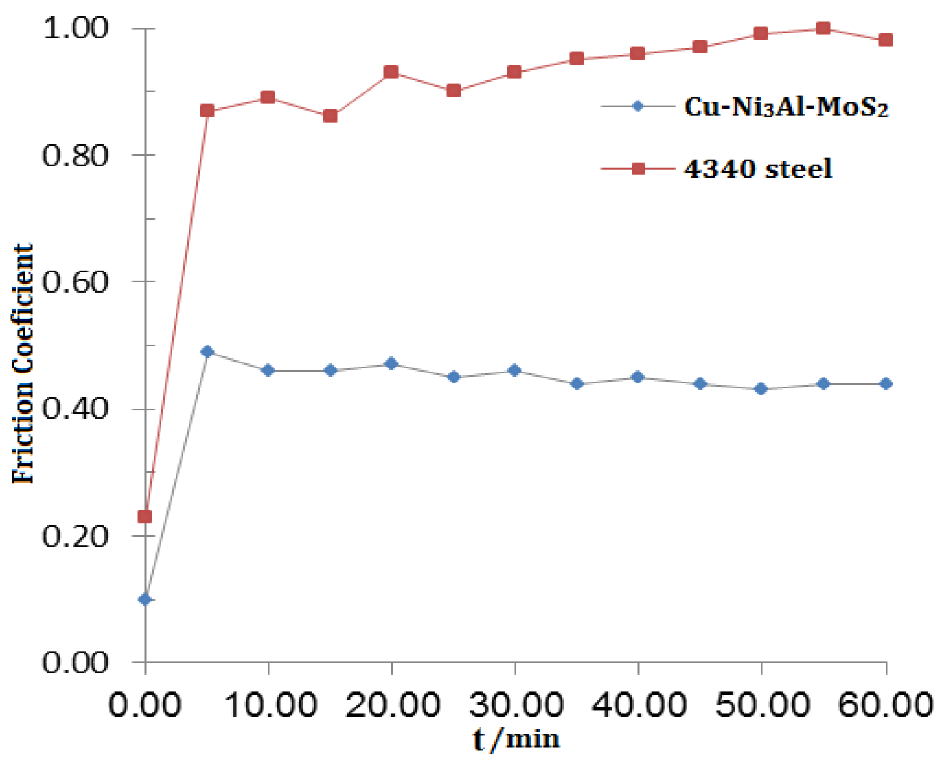


Fig. 10. Friction coefficients of the composite coating.

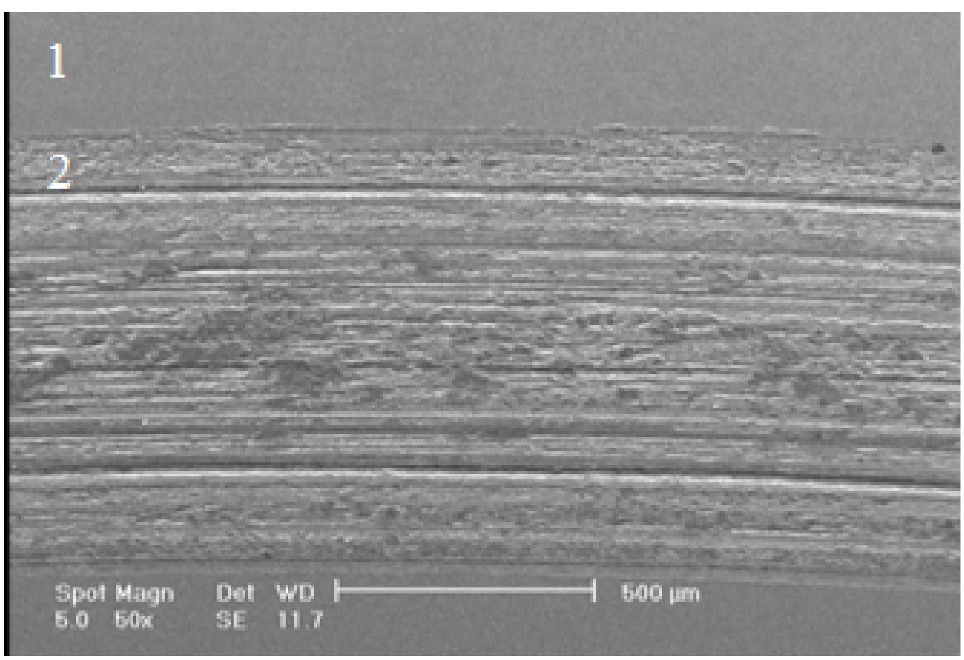


Fig. 11. SEM picture from the contacting area on the ball.

revealed that the friction reduction and wear improved at room temperature.

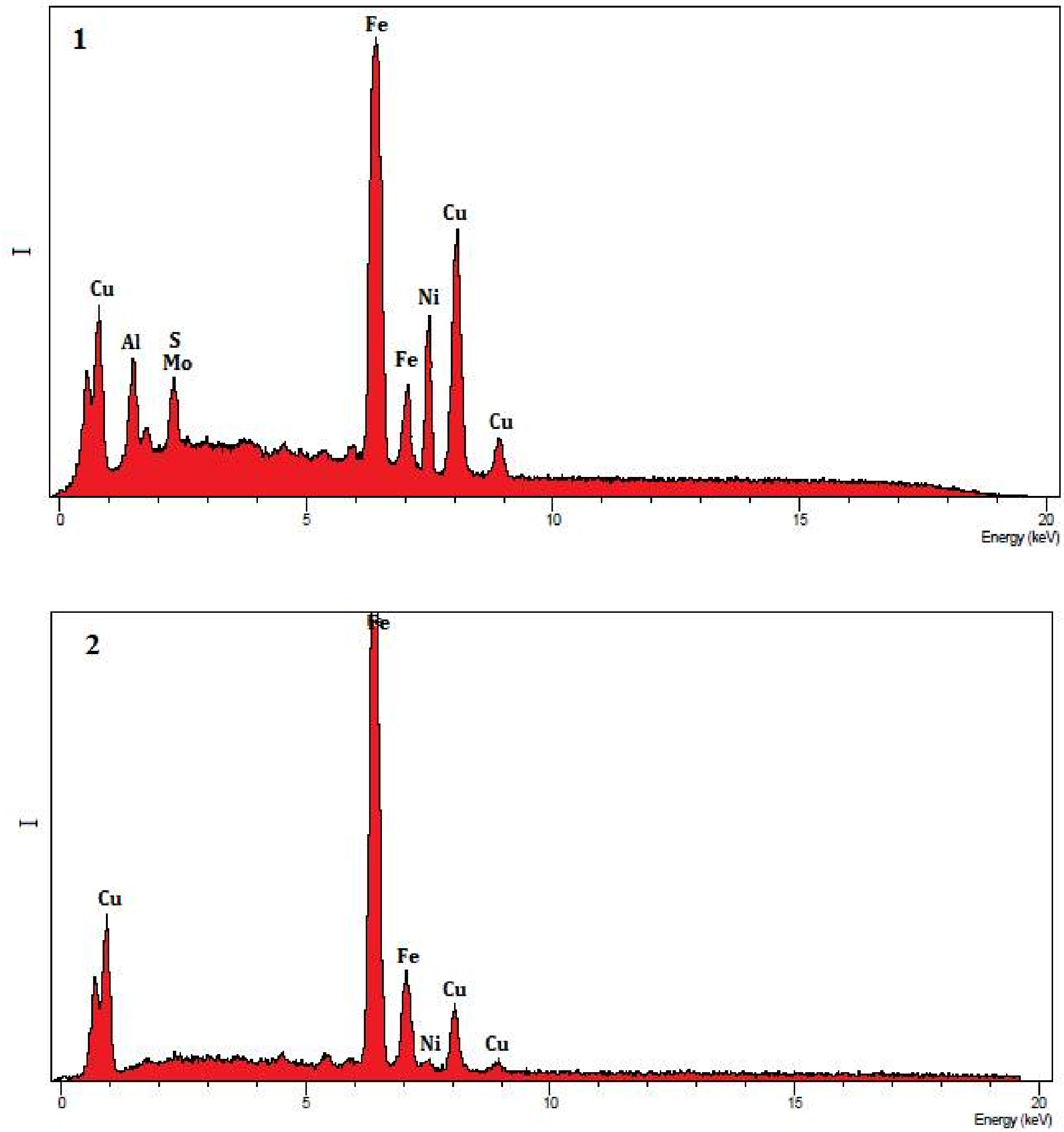


Fig. 12. EDS analysis from the wear scars

4. Conclusions

The Cu-Ni_3Al-MoS_2 composite coating was successfully prepared by magnetron sputtering. Different test results indicated a quite smooth surface of the coating with good strength of adhesion to the substrate. In addition, it has been

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