# High-temperature tribological properties of NiCoCrAlY-$WSe_2$-$BaF_2$·$CaF_2$ solid lubricant coatings prepared by plasma spraying

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**Abstract.** In this paper, NiCoCrAlY-$WSe_2$-$BaF_2$·$CaF_2$ solid lubricant coatings were produced on a substrate by plasma spray and investigated at the high temperature, such as 500℃ and 800℃. The structure of the coatings was characterized using XRD pattern and scanning electron microscopy. The TC1 (83wt% NiCoCrAlY) coating has a low friction coefficient at 500℃, where the $WSe_2$ is a good solid lubricant. The TC2 (65wt% NiCoCrAlY) coating has the low friction coefficient (0.279) at 800℃, due to the formation of BaCrO4 on the surfaces. As a result, the TC2 coating has the optimal tribological property in the wide temperature.

## 1. Introduction

High-temperature self-lubricant coating which has well mechanical and tribological properties at 25~1000℃ was a hotspot in the industry [1-3]. Recently, several lubricant coatings were researched. Where, in the solid lubricant coatings, the silver and barium-calcium fluoride eutectic was added to the binder and act as high-temperature lubricants. The composite coatings of PM212/PS212, PS300, PS400 were composed of a good matrix (NiCr-$Cr_3C_2$, or NiCr-$Cr_2O_3$) and Ag with $BaF_2$·$CaF_2$ eutectic solid lubricants [4-7]. Research of the coatings indicates that the lubricious glaze formed in the surface of coatings to achieve low friction and wear rate of a high wide temperature range. However, at room temperature, the wear rate of the coatings is even high that the lubricious glaze was destroyed. Above 800℃, the oxidation and the decline of the mechanical property degraded its wear resistance [8-11].

So, in order to obtain optimal friction property of lubricant coatings at wide temperature range, the NiCoCrAlY-$WSe_2$-$BaF_2$·$CaF_2$ coatings were fabricated on the substrates of ASTM4145 alloy steel. The tribological properties of the composite coatings were tested at temperature 500℃ and 800℃.

## 2. Experimental procedure

NiCoCrAlY-$WSe_2$-$BaF_2$·$CaF_2$ composite powders with a different content was listed in Tab.1, which involve NiCoCrAlY, $BaF_2$, $CaF_2$, $WSe_2$, Y, and BN with a mean grain size of 5-80μm. The solid lubricant coatings were deposited by HT-80 atmospheric plasma spray system (HT-80 Plasma Spray System, Beijing Aerospace Zhenbang Pml Precision Mechanism Ltd.). The substrate is ASTM5145 alloy steel.

The tribological property was tested on a CSM high-temperature tribometer (CSM Co. Rue de la Gare4 Galileo Center Ch-2034 Peseux, Switzerland). For pre-testing, the sample disk (Φ30mm×8mm) surfaces were cleaned with acetone. A commercial $Al_2O_3$ ceramic ball, which was 6mm in diameter, was also used. The test was performed with a normal load of 10 N and a sliding velocity of 0.24 m/s for 60 min. The test temperature was set as 500°C and 800°C, respectively.

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The microstructure of worn surface at different temperature for NiCoCrAlY-$WSe_2$-$BaF_2$·$CaF_2$ composite coatings were characterised using scanning electron microscopy (SEM; JSM-5600LV; JEOL, Tokyo, Japan), energy dispersal spectroscopy (EDS; Kevex Corp, Foster City, CA), and XRD spectrum (XRD; Philips X' Pert-MRD X-ray diffract-meter, 40 kV, 30 mA) with Cu Ka radiation over an angular range of 10° ≤2θ≤ 90°.

**Table 1.** Compositions of the spray NiCoCrAlY-$WSe_2$-$BaF_2$·$CaF_2$ composite particle.

| No. | NiCoCrAlY | $BaF_2$ | $CaF_2$ | $WSe_2$ | Y | BN |
|---|---|---|---|---|---|---|
| TC1 | 83% | 4.67% | 2.33% | 7% | 3% | - |
| TC2 | 65% | 12.3% | 9.8% | 5.9% | 3% | 4% |

## 3. Results and discussions

### *3.1. High-temperature tribological property of the NiCoCrAlY-$WSe_2$-$BaF_2$·$CaF_2$ composite coatings*

Friction coefficients of TC1 and TC2 coatings at 500℃ and 800℃ were listed in Tab.2. From the Tab.2, it can be seen that the average friction coefficient of TC1 coatings are about 0.440 at 500℃ and 0.461 at 800℃. The friction coefficient of the TC2 coatings was 0.748 and 0.279 at 500℃ and 800℃, respectively. Where, the TC2 coating at 500℃ has the higher friction coefficient because $BaF_2$·$CaF_2$ cannot possess tribology property for the brittle structure. However, the experiment result shows that $WSe_2$ is an optimal solid lubricant phase at 500℃. At 800℃, the friction coefficient was decreased to 0.279, And, the wear rate of TC1 solid lubricant coatings are $22.5\times10^{-5}$($mm^3$/N·m) and $5.47\times10^{-5}$($mm^3$/N·m) at the different temperature, that of TC2 solidi lubricant coatings are $11.6\times10^{-5}$($mm^3$/N·m) and $2.54\times10^{-5}$($mm^3$/N·m), respectively. Especially, the low tribological property of TC2 coatings was obtained.

**Table 2.** Friction coefficient of TC1 and TC2 coatings at different temperature.

| Sample No. | Temperature (℃) | Friction coefficient | Wear Rate ($\times10^{-5}$($mm^3$/N·m)) |
|---|---|---|---|
| TC1 | 500 | 0.440 | 22.5 |
| TC1 | 800 | 0.461 | 5.47 |
| TC2 | 500 | 0.748 | 11.6 |
| TC2 | 800 | 0.279 | 2.54 |

At 500℃, The XRD results show that there was not oxidized in the NiCoCrAlY-$WSe_2$-$BaF_2$·$CaF_2$ lubricant coatings; most of phase in the coatings keep the original statement. Comparably, at 800℃, the $BaF_2$ and $CaF_2$ peaks does not exist in the XRD pattern instead of the $BaCrO_4$. All of them were proved as the good solid lubricants. Especially, the $BaCrO_4$ with the baritone structure has a good lubricating property at high temperature.

### *3.2. Worn surface of the NiCoCrAlY-$WSe_2$-$BaF_2$·$CaF_2$ composite coatings at high temperature*

Fig.2 shows the worn surfaces of the TC1 coatings. From Fig.2(a, b), at 500℃, the surfaces are rough, some dispersed particles and grooves existed in the wear region, which indicates that wear could depend on the delamination. From Fig. 2(c, d) (at 800℃), a relatively smooth surface can be taken, where some oxidation leads to the formation of the glaze layer.

The worn surfaces of TC2 coatings were shown in the Fig.3. It was noted that the detachment in the rich $BaF_2$·$CaF_2$ areas indicates that the wear mechanism is micro-fracture and delamination at 500℃ (shown in Fig.3 (a b)). At 800℃, relatively smooth surface form, many fine grooves, and deformed surfaces are present along slide direction, which takes on the micro-plough with deformation and delamination (shown in Fig.3(c, d)).

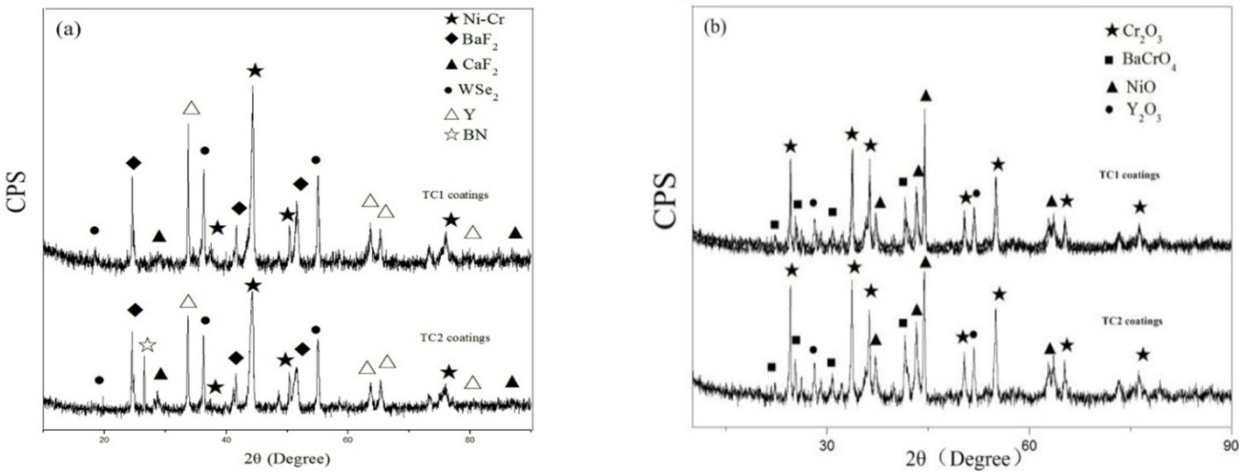


**Figure 1.** XRD patterns of the NiCoCrAlY-$WSe_2$-$BaF_2$·$CaF_2$ composite coatings (a) 500℃; (b) 800℃.

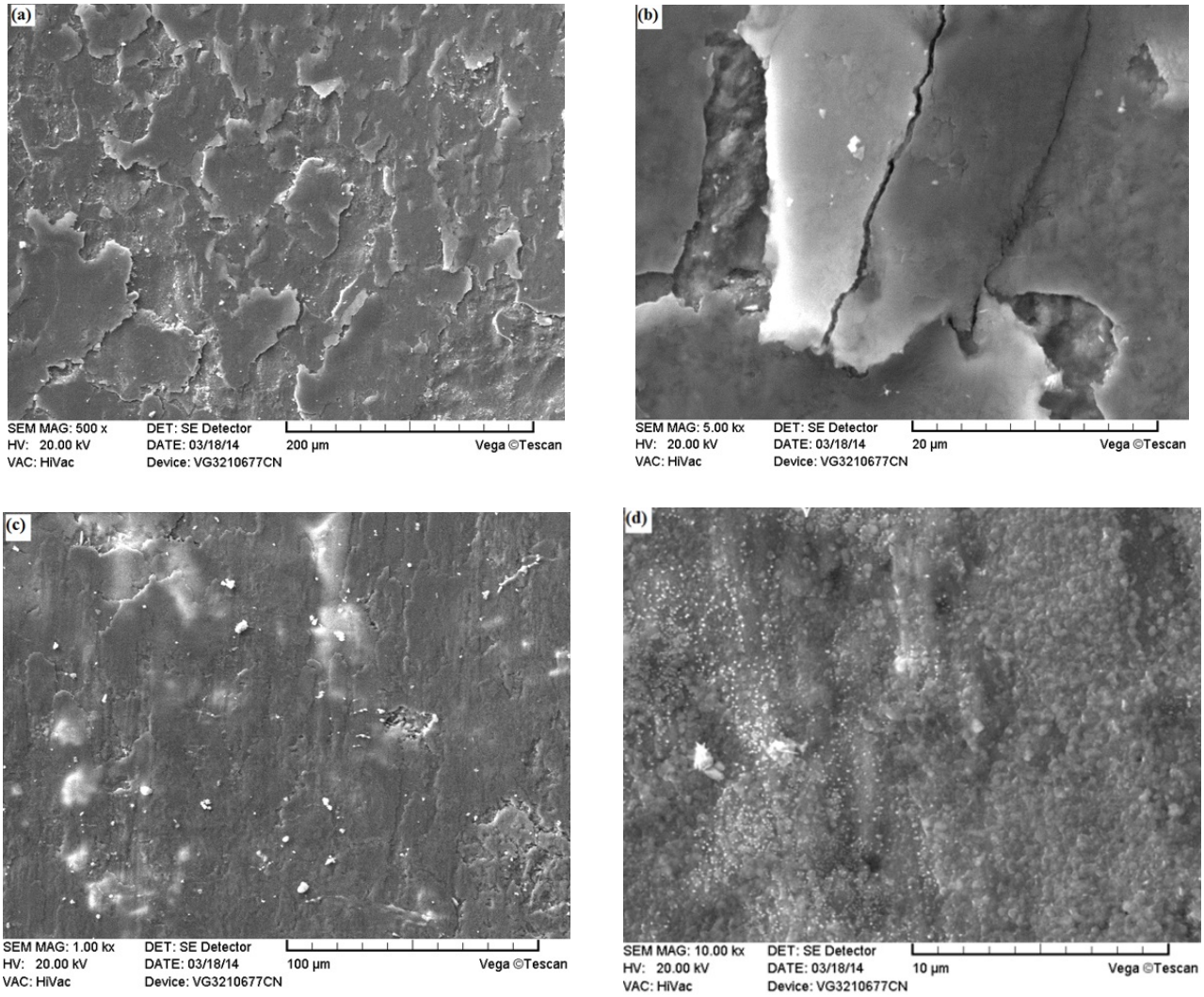


**Figure 2.** Worn surface of TC1 coatings at high temperature: (a, b) 500℃; (c, d) 800℃.

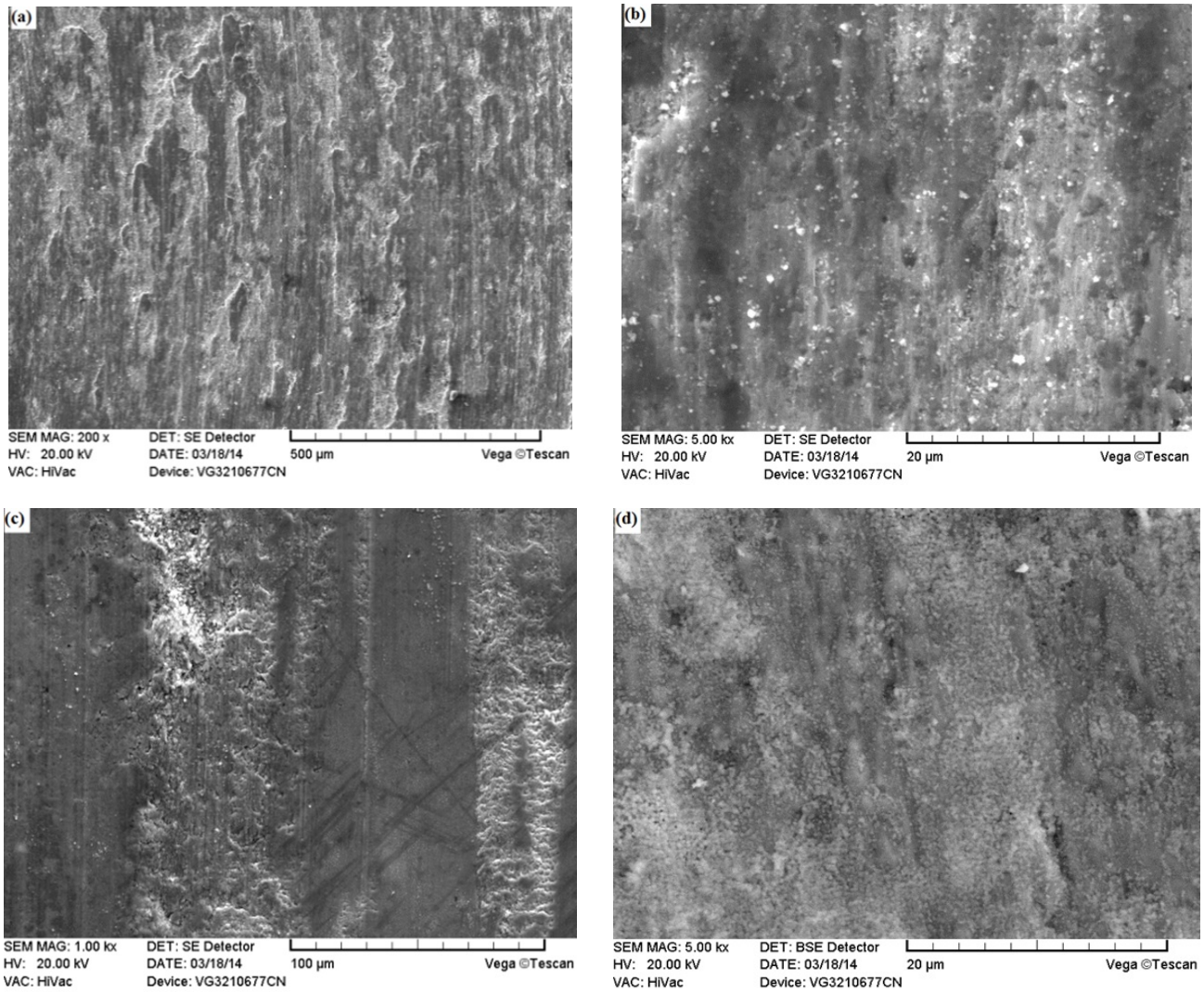


**Figure 3.** Worn surface of TC2 coatings at high temperature: (a, b) 500℃; (c, d) 800℃.

### *3.3. High-temperature wear mechanisms of the NiCoCrAlY-$WSe_2$-$BaF_2$·$CaF_2$ composite coatings*

The results demonstrate that the TC1 coatings have better self-lubricating properties at 500℃, and the TC2 coatings have the better performance at friction and wear-resistant properties at 800℃. When the temperature is low (such as 500℃), the $WSe_2$ acts as the lubricant phase in the coatings, TC1 coating has more, so it has a low average friction coefficient at 500℃. When the temperature comes to 800℃, the $WSe_2$ is disabled; the $BaF_2$ and $CaF_2$ play the role instead. The phase changes on the surfaces of TC1 coatings at 800℃, they are the oxidant, and the film is on the surface of coatings so as to wear easily. The debris on the sliding surfaces was effected on the friction pair, and the structure characteristic of the coatings.

The self-lubricant property of the NiCoCrAlY-$WSe_2$-$BaF_2$·$CaF_2$ composite coatings in a wide temperature was consisted of $BaF_2$·$CaF_2$ and $WSe_2$. At the lower temperature, the $WSe_2$ act as solid lubricants. At high temperature, the TC2 coating has the highest friction coefficient at 500℃. At 800℃, the TC2 coating has the lowest friction coefficient. Where, the new production, $BaCrO_4$, provides an excellent tribological property at high temperature [12]. Moreover, the compactness of the coatings at high temperature (at 800℃) is bad contrast to them at 500℃ for the decomposition of $WSe_2$. So, there are some pores in the coatings.

## 4. Conclusions

- The high-temperature tribological properties of NiCoCrAlY-$WSe_2$-$BaF_2$·$CaF_2$ composite coatings prepared by Plasma Spraying were researched. The TC2 (65wt% NiCoCrAlY) coating shows a better friction property at high temperature.

- At 800℃, the production, $BaCrO_4$, provides an excellent lubricating property due to the tribo-chemical reaction at high temperature.
- The low friction coefficient of the TC2 coatings at 800℃ is due to the balance between the mechanical and lubricity of the worn surface.

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