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Maciej ŁUSZCZ[*], **Remigiusz MICHALCZEWSKI**[**], **Marek KALBARCZYK**[***], **Edyta OSUCH-SŁOMKA**[****], **Jarosław MOLENDA**[*****], **Le LIU**[******], **Maksim ANTONOV**[*******], **Irina HUSSAINOVA**[********]

EFFECT OF HBN ON WEAR OF AlCrN-COATED SPARK PLASMA-SINTERED TiB_2/Ti COMPOSITES AT TEMPERATURES UP TO 900°C

WPŁYW HEKSAGONALNEGO AZOTKU BORU NA PROCES ZUŻYWANIA W TEMPERATURZE DO 900°C KOMPOZYTÓW TiB_2/Ti SPIEKANYCH ISKROWO-PLAZMOWO, POKRYTYCH POWŁOKĄ AlCrN

Key words: TiB_2/Ti composites, AlCrN coatings, PVD, hexagonal boron nitride, spark plasma sintering, wear, high-temperature, cermet.

Abstract: In this work, hexagonal boron nitride powder was used for the lubrication of an interface of TiB_2/Ti composite protected by an AlCrN coating and a ceramic Si_3N_4 ball. The wear behaviour of this tribo-pair in an oscillating motion was studied with an SRV tribotester at the temperature range from room temperature to 900°C. The action of hexagonal boron nitride as a solid lubricant was analysed with the use of a 3D microscopy and energy-dispersive spectroscopy. The test results confirmed that under high-temperature conditions, the use of hexagonal boron nitride as a solid lubricant does not increase the wear resistance of the TiB_2/Ti composite. The use of the AlCrN coating significantly reduces wear at the temperature up to 600°C only, while the combined use of the AlCrN coating and hBN lubrication provides effective protection against wear even at the temperature up to 900°C. Therefore, the synergy of the anti-wear action of the coating and the solid lubricant was proved.

Słowa kluczowe: kompozyty TiB_2/Ti, powłoki AlCrN, metoda PVD, heksagonalny azotek boru, iskrowe spiekanie plazmowe, zużycie, wysoka temperatura, cermet.

Streszczenie: W niniejszej pracy wykorzystano heksagonalny azotek boru (hBN) jako smarującą międzywarstwę między podłożem kompozytowym z TiB_2/Ti chronionym powłoką AlCrN a przeciwpróbką – kulką ceramiczną wykonaną z Si_3N_4. Testy tribologiczne wykonano z zastosowaniem stanowiska SRV. Zbadano zużycie ścierne w ruchu oscylacyjnym w zakresie od temperatury pokojowej do 900°C. Rola hBN jako stałego środka smarowego została zbadana z wykorzystaniem mikroskopii 3D oraz spektroskopii rentgenowskiej z dyspersją energii. Wyniki przeprowadzonych badań potwierdziły, że w warunkach wysokich temperatur zastosowanie heksagonalnego azotku boru pełniącego funkcję smaru stałego nie powoduje zwiększenie odporności na zużycie kompozytu TiB_2/Ti. Zastosowanie powłoki AlCrN powoduje znaczącą redukcję zużycia jedynie do temperatury 600°C, podczas gdy łączne zastosowanie powłoki AlCrN i smarowania hBN stanowi skuteczną ochronę przed zużyciem nawet do 900°C. Wykazano zatem synergię przeciwzużyciowego działania powłoki i smaru stałego.

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[*] ORCID: 0000-0003-1796-9195. Łukasiewicz – Institute for Sustainable Technologies, Tribology Center, K. Pułaskiego 6/10 Street, 26-600 Radom, Poland.

[**] ORCID: 0000-0002-9199-616X. Łukasiewicz – Institute for Sustainable Technologies, Tribology Center, K. Pułaskiego 6/10 Street, 26-600 Radom, Poland.

[***] ORCID: 0000-0003-0286-5705. Łukasiewicz – Institute for Sustainable Technologies, Tribology Center, K. Pułaskiego 6/10 Street, 26-600 Radom, Poland; Faculty of Mechanical Engineering, Kazimierz Pulaski University of Technology and Humanities in Radom, E. Stasieckiego 54 Street, 26-612 Radom, Poland.

[****] ORCID: 0000-0002-2302-2646. Łukasiewicz – Institute for Sustainable Technologies, Tribology Center, K. Pułaskiego 6/10 Street, 26-600 Radom, Poland.

[*****] ORCID: 0000-0003-3477-4971. Łukasiewicz – Łukasiewicz – Institute for Sustainable Technologies, Bioeconomy and Ecoinnovation Centre, K. Pułaskiego 6/10 Street, 26-600 Radom, Poland.

[******] ORCID: 0000-0003-3249-890X. Tallinn University of Technology, Department of Mechanical and Industrial Engineering, Ehitajate tee 5, 19086 Tallinn, Estonia.

[*******] ORCID: 0000-0002-4302-6708. Tallinn University of Technology, Department of Mechanical and Industrial Engineering, Ehitajate tee 5, 19086 Tallinn, Estonia.

[********] ORCID: 0000-0003-3081-2491. Tallinn University of Technology, Department of Mechanical and Industrial Engineering, Ehitajate tee 5, 19086 Tallinn, Estonia.

INTRODUCTION

Many high-temperature manufacturing processes are performed under uncontrolled friction conditions, which leads to heavy energy consumption and high wear. A possible solution to control friction at temperatures reaching 900°C is to rely on high heat resistant materials and protective coatings designed to interact with solid lubricants. Interest in the study of materials for high-temperature tribo-applications has been considerably growing since the early 1970s. However, the temperature range for effective lubrication for many materials has not been determined yet, and the statements found in literature are often contradictory.

There is a great potential in the application of Ti-based composites as a substitute for currently used steel alloys, tungsten carbide-based composites and cemented carbide substrates **[L. 1–3]**. Many studies employing laser surface processing, coatings deposition or reinforcement incorporation have been carried out to improve the wear performance of Ti-based composites. Titanium monoboride (TiB), which has excellent thermodynamic and chemical stability with a Ti matrix, is one of the most widely used additives. At high temperatures, this cermet reacts with humidity from the air, forming boric acid with good lubricating properties **[L. 2, 4]**. Several methods to fabricate titanium-based bulk composites have come into picture in the recent years, including the selective laser sintering, the hot isostatic pressing, the vacuum sintering, the spark plasma sintering (SPS) or the field-assisted sintering technique (FAST). According to the recent studies, the 50 wt%Ti–50 wt%TiB_w ceramic-metal composite is an attractive candidate for a wide variety of applications, not only at room temperature, but also at elevated and high temperatures, especially under conditions, where good wear resistance is required. In high-temperature tests conducted in sliding conditions, in situ appearance of boric acid reduces frictional wear **[L. 2, 4]**. A decrease in the wear rate and friction coefficient is observed at 800°C. The presence of a protective tribooxide layer and lubricious boric acid on the composite surface at 800°C was confirmed. However, most of high-temperature real applications concern not only unidirectional sliding conditions but also oscillating. The latest study proved that the same composite in oscillating conditions wears out significantly faster with grain tearout **[L. 5, 6]**.

The wear properties of composites can be improved by the deposition of a PVD coating as an additional protection, and the application of suitably selected solid lubricants. An AlCrN hard coating, which has very good high-temperature properties, is one of the possible solutions. AlCrN is a common protective coating in the tool industry due to its high oxidation resistance and thermal stability **[L. 6–8]**. An extensive research has been conducted on these coatings in the direction of the deposition techniques, coating structure, mechanical properties, and oxidation characteristics; however, their tribological behaviour has been mainly investigated at dry conditions **[L. 6, 9–10]**.

There are many potential high-temperature solid lubricants: soft metals (e.g. Ag, Bi, Au, Cu, In) and laminar solids (i.e. layered lattice compounds, e.g.: molybdenum disulfide, graphene, hexagonal boron nitride, tungsten disulfide or alkaline-earth fluorides) **[L. 11]**. As regards applications at very high temperature, hexagonal boron nitride (hBN) seems to be the most suitable solution. It is an extraordinary material due to its physical and chemical properties. The hBN with a structure similar to graphite demonstrates the same lubrication mechanism, i.e. its easily sheared layers held by weak van der Waals forces provide low resistance to slide. It is regarded as a self-lubricating compound. The interest in hBN arises from its high oxidation resistance, i.e. 1000°C in air and 1400°C in vacuum, in comparison to graphite, which oxidizes at 450°C in air. Other properties, such as high thermal conductivity, chemical stability, and oxidation resistance, make it suitable for high-temperature usage.

The creation and action of a tribo-layer during high temperature friction of hexagonal boron nitride remains unclear and inconclusive for AlCrN-coated spark plasma-sintered TiB_2/Ti composites. The aim of the present work is to recognise the high-temperature tribological bahaviour of an AlCrN-based coating, deposited on a new type cermet substrate, against an Si_3N_4 counter sample, with the use of a solid lubricant – hexagonal boron nitride.

MATERIALS AND METHODS

TiB_2/Ti composite

TiB_2/Ti composites are cermet materials designed for high temperature working conditions. They merge titanium alloy properties like corrosion resistance, high strength-to-weight ratio, and toughness, with titanium boride hardness, and excellent tribological behaviour **[L. 12]**. Samples were manufactured with the SPS method (Spark Plasma Sintering) (FCT Systeme GmbH, Sonneberg, Germany) (**Table 1**) from TiB_2 and Ti powders with the weight ratio of approximately 50–50%. The selected preparation method enables sintering of high-melting borides and helps to reduce the process temperature. Precursors were conventionally pre-mixed. As a result, 25 mm in diameter and 9 mm in thickness cylindrical samples were obtained. After sintering, graphite scale has been taken off and the surface has been polished to Ra = 0.091±0.008 µm, (details are given in **[L. 13]**).

Table 1. SPS process parameters applied for TiB_2/Ti composite sintering
Tabela 1. Parametry procesu SPS zastosowane do spiekania kompozytu TiB_2/Ti

SPS process parameters	Heating rate	Sintering temperature	Sintering time	Pressure
Value	100°C/min	1250°C	15 min	50 MPa

AlCrN coating

Insufficient tribological behaviour of a composite in oscillating motion requires improvement in high-temperature wear resistance. Coating deposition **[L. 14–17]**, among other methods, is one of those which help to enhance surface properties and protect the substrate from severe operating conditions **[L. 9–10, 18–19]**.

The AlCrN-based commercial coating (BALINIT® ALCRONA PRO made by Oerlikon Balzers, Polkowice, Poland) was deposited on samples by means of the Physical Vapour Deposition (PVD) method. This coating provides superb tribological characteristics at temperatures exceeding 1,000°C **[L. 6–8]**. The coating properties are summarised in **Table 2**.

Table 2. AlCrN coating deposited on TiB_2/Ti composite characterisation
Tabela 2. Właściwości powłoki AlCrN osadzonej na kompozycie TiB_2/Ti

Parameter	Chemical composition [at. %]			Hardness [HV(0,05)]	Thickness [µm]	Scratch test results: Load [N]		
	Al	Cr	N			Lc1	Lc2	Lc3
Value	36.9±0.2	39.1±0.2	21.2±0.3	3200	1.2–1.3	28.0	38.5	77.8

Chemical composition was measured with a scanning electron microscope (SEM) (SU-70 Schottky emission, Hitachi, Tokyo, Japan) with an EDS attachment.

Adhesion of an AlCrN coating was measured with the Rockwell C type intender (REVETEST Scratch-Tester, manufactured by Anton Paar GmbH, Graz, Austria). Test parameters were established at an angle of 120°, 0.2 mm tip radius, incremental loading rate of 10 N/mm, scratch length of 10 mm, progressive load from 0 to 100 N, and the scratch speed of 10 mm/min. The Lc1 critical load corresponds to brittle tensile cracking, Lc2 denotes first delamination and chipping, and Lc3 points the moment of substrate exposure and total coating removal.

Solid lubricant

Hexagonal boron nitride is used as an anti-seize agent and also as a high-temperature solid state grease. A significant advantage of this material is not only its high thermal resistance, but also the fact that it has a graphite-like structure with hexagonal rings characterised by strong chemical bonds and weak interlayer molecular interactions **[L. 11, 20–21]**. Such structure facilitates hexagonal layers shearing, which reduces the coefficient of friction and wear. This properties make the hBN a promising high-temperature lubricant **[L. 22–23]**. There are different deposition methods, such as spraying or brush application. **[L. 20–21, 24]**.

Aerosol of hBN (HeBoCoat® SL-E 200, Henze, Germany) was selected for an effortless deposition of a thin homogenous layer of a lubricant. This method helps to obtain a reproducible layer on manufactured specimens. The disadvantage of such type of application is the need to determine how much time is required for the solvent to evaporate, as it is important to ensure a sufficient interval between the hBN deposition and the start of a tribological test. To answer this question, FTIR spectra were recorded (FTIR-6200, Jasco, Japan equipped with an Attenuated Total Reflectance (ATR) attachment). Measurement parameters are listed in the **Table 3**.

Aerosol was sprayed on the ZnSe monocrystal and subject to a series of analyses conducted at 5-minute intervals. This made the observation of the kinetics of the solvent evaporation (i.e. ethyl alcohol from the applied lubricating layer) possible, which was determined by calculating the area between the reference line and the curve in the wavenumber range of 3700–3030 cm^{-1}, in which there is a minimum related to the stretching vibrations of the O-H bond in the alcohol hydroxyl group. The integration range of the spectral band is presented visually in **Fig. 1**. The obtained results were plotted against time, creating the curve of the evaporation kinetics (**Fig. 2**).

Table 3. FTIR measurement parameters
Tabela 3. Parametry pomiaru FTIR

Parameter	Spectral range [cm^{-1}]	Spectral resolution [cm^{-1}]	Number of scans [-]	Detector type
Value	4000–650	4	30	Triglycine Sulfate Crystal (TGS)

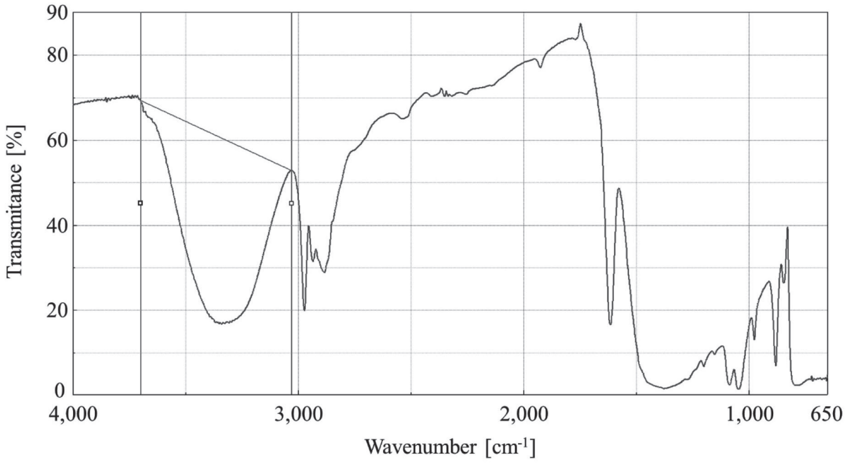

Fig. 1. FTIR spectra obtained for a deposited hBN-spray with the integration range of the spectral band considered for the calculation of the evaporation kinetics marked
Rys. 1. Widmo FTIR uzyskane dla napylonego smaru hBN bezpośrednio po naniesieniu. Zaznaczono zakres widma uwzględniony przy obliczaniu kinetyki odparowania

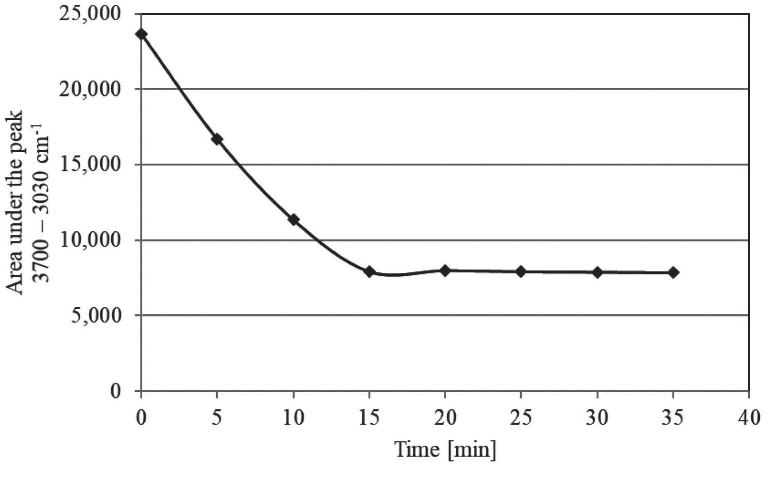

Fig. 2. hBN-spray solvent evaporation kinetics obtained in measurements for as deposited spray and repeated every 5 minutes, up to 35 minutes
Rys. 2. Kinetyka odparowania rozpuszczalnika z napylanego hBN uzyskana z pomiarów bezpośrednio po naniesieniu, następnie co 5 minut aż do 35 minut

As shown in the graph, the curve turns into a constant function slightly before the 20th minute, which indicates the full evaporation of the alcohol from the aerosol sample. For the purpose of the wear investigation, the 20-minute interval between the hBN application and the test start was selected as sufficient.

Wear Tests Methodology

The tribological experiments were carried with a high-temperature reciprocating friction and wear SRV test machine (Optimol Instruments Prüftechnik GmbH, Munich, Germany) (**Fig. 3**). This machine utilises an electromagnetic drive to oscillate an upper specimen under normal load against a stationary test specimen. The normal load is applied by means of a servomotor. The test parameters (**Table 4**) were applied in accordance with the previous research **[L. 25]**. All experiments were repeated at least three times.

Table 4. Selected test parameters in the SRV test
Tabela 4. Wybrane parametry testu SRV

Parameter	Value
Test temperature [°C]	25, 200, 400, 600, 750, 900
Load [N]	5
Stroke length [µm]	1.000
Frequency [Hz]	10
Test duration [s]	300
Heating rate [°C/s]	1
Temperature stabilization time [s]	1.200
Counter sample ball diameter [mm]	10
Ball material [-]	Si_3N_4

Wear scars were measured using an optical profilometer (Talysurf CCI-Lite Non-contact 3D Profiler with TalyMap software, Taylor Hobson Ltd., Leicester, UK) and a measuring microscope (MM-40, Nikon).

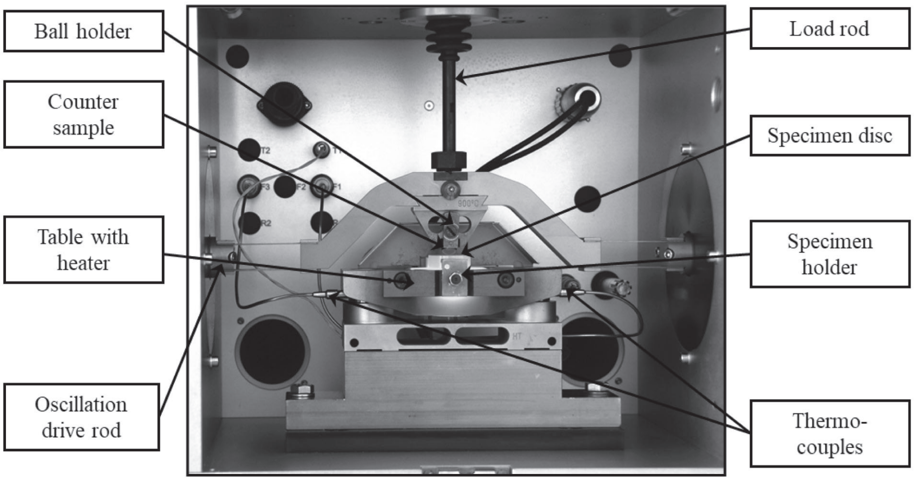

Fig. 3. Ball-on-disc SRV oscillating tribosystem
Rys. 3. Tribosystem urządzenia SRV dla testów oscylacyjnych układu kula–tarcza

Sample's surface was investigated with a scanning electron microscope (SEM) with secondary electron (SE) and back-scattered electron (BSE) detection (SU-70 Schottky emission, Hitachi, Tokyo, Japan) with an EDS attachment at an accelerating voltage of 15 kV. The atomic content of chemical elements inside and outside of the wear track was investigated. At least three spot measurements were used to obtain mean values of the concentrations.

RESULTS AND DISCUSSION

The substrate composite was taken as a reference material for wear tests. The results for the TiB_2/Ti composite with and without hBN sprayed on, are illustrated in **Fig. 4**. The volumetric wear increases at each temperature step from 25 up to 900°C.

The maximum wear track depth follows the volumetric wear at the temperature up to 750°C, and then it goes down at the highest temperature.

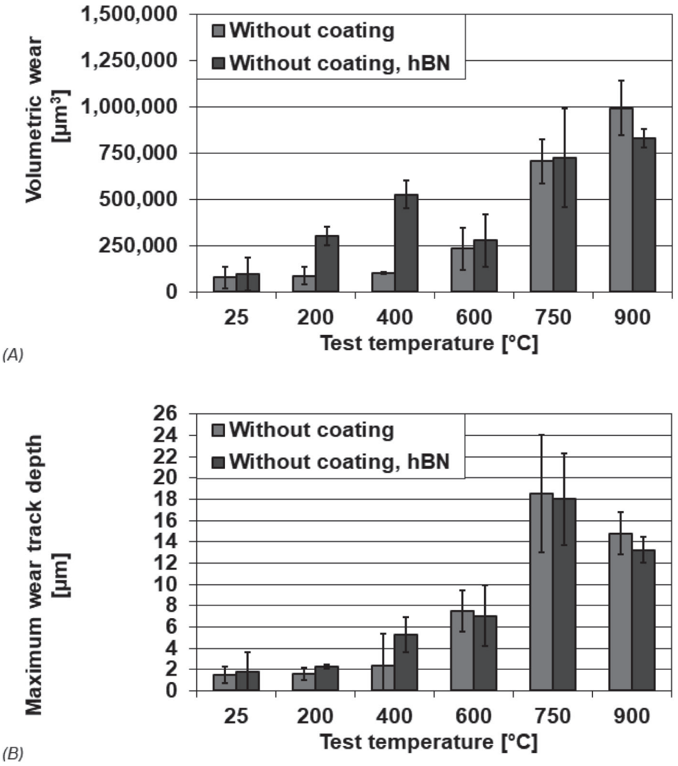

Fig. 4. SRV tests results: volumetric wear (A) and maximum wear track depth (B) for TiB_2/Ti composite and composite with solid state lubricant hBN obtained with an interferometer

Rys. 4. Wyniki testów SRV uzyskane z wykorzystaniem profilometru optycznego: zużycie objętościowe (A) oraz maksymalna głębokość śladu wytarcia (B) dla kompozytu TiB_2/Ti oraz kompozytu smarowanego smarem stałym hBN

The wear of the composite is moderate at the temperature up to 400°C, and at higher temperatures it is several times higher. The presence of the solid lubricant correlates with higher volumetric wear and maximum track depth at test temperatures up to 400°C. The positive effect of the presence of hBN is visible at 900°C, but even in this case, the decrease in wear is not significant. Furthermore, extremely deep holes are observed at wear track (even several microns in depth) at the temperature of 750°C and 900°C, which is typical for fatigue wear. The increase in test temperature leads to a change from abrasive mode regime to a fatigue one. In general, the application of a solid lubricant (hBN) to a tribosystem consisting of a TiB_2/Ti composite and ceramic ball (Si_3N_4) does not prevent wear at a high temperature.

The measurements of wear for a coated substrate are presented in **Fig. 5**. AlCrN coating deposition on TiB_2/Ti substrate provides fairly low and stable wear at the temperature up to 600°C, at which the volumetric wear is more than two times lower if the AlCrN is used, and decreases even more when the hBN lubrication is added. At the two highest steps: i.e. at 750 and 900°C, if the use of coating is combined with lubrication, the effect of wear reduction is the most significant. The use of double anti-wear protection of the composite results in a synergetic increase in wear resistance for the entire temperature range in the performed tests.

Data obtained from the interferometer were confirmed by a microscopic analysis. The microscopic images of wear tracks of the composite tested at different temperatures are presented in **Fig. 6**. From 600°C, large number of extensive grain tearouts are observed. The use of the hBN lubrication slightly reduces the number of pits.

Optical microscope images of the wear tracks of the AlCrN-coated specimens, obtained at different temperatures, are presented in **Fig. 7**.

As far as the most difficult conditions are considered (750–900°C), the volumetric wear of

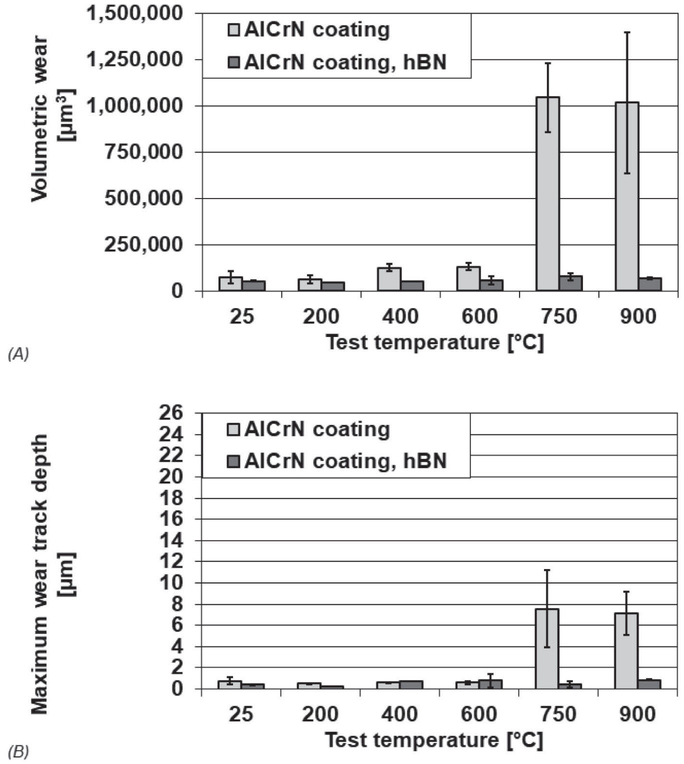

Fig. 5. SRV tests results: volumetric wear (A) and maximum wear track depth (B) for TiB_2/Ti composite coated with AlCrN coating and a composite coated with solid state lubricant hBN obtained with an interferometer

Rys. 5. Wyniki testów SRV uzyskane z wykorzystaniem profilometru optycznego: zużycie objętościowe (A) oraz maksymalna głębokość śladu wytarcia (B) dla kompozytu TiB_2/Ti pokrytego powłoką AlCrN oraz kompozytu z powłoką smarowanego smarem stałym hBN

the AlCrN-coated samples does not differ from the uncoated ones; however, there a significant reduction in the number and size of pits can be seen. In the images obtained for the coated specimens lubricated with hBN, no signs of a substrate material can be observed, even at the highest temperature. Also, the surface of the balls does not exhibit any material transfer. In this case, the coating is effectively protected against wear.

To present the differentiation in the wear process caused by the coating deposition and hBN application, the set of cross-sections from the wear tracks obtained at 750°C is presented in **Fig 8**. Each profile runs through the deepest valley of the particular wear track.

The deepest grain tearouts are present on an uncoated composite (**Fig. 8A**). Spraying with a solid state lubricant should reduce wear, but it only reduces the number of torn out grains (**Fig. 8B**), which results only in a slight reduction of the trace depth. As for a composite with AlCrN, the coating is worn through (**Fig. 8C**), but the wear track is much shallower than in the case of uncoated specimens. The application of hBN reduces trace depth in the multi-fold manner, hence co-causing the synergic effect of wear resistance increase (**Fig. 8D**).

Aiming on the recognition of wear prevention mechanism, the chemical surface analysis were performed by means of EDS. The selection of samples was narrowed to the ones which operated at 600 and 750°C, as at this temperatures the most diverse tribological behaviour took place. Results are shown in **Tables 5** and **6**.

In the case of uncoated composites, the oxidation takes place at both temperatures. At 750°C, at the surface of the composite, outside the wear track, the content of oxygen increases. The application of hBN affects the oxidation process negligibly. The highest contents of oxygen and

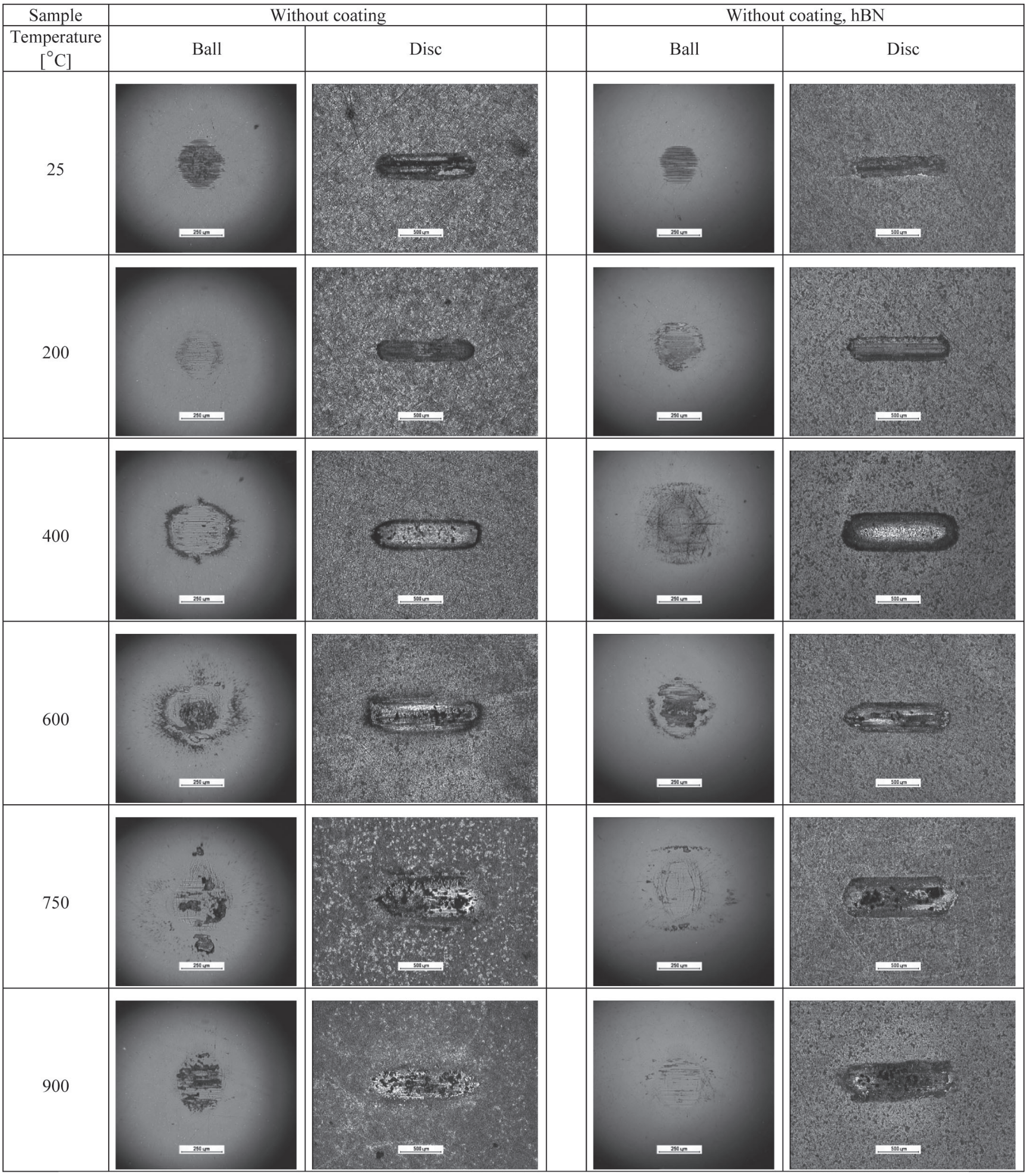

Fig. 6. Microscopy images of composite specimens and counter samples wear tested on the SRV tribotester

Rys. 6. Mikroskopowe zdjęcia próbek kompozytu oraz przeciwpróbek po testach na tribotesterze SRV

titanium indicate that the phase of titanium oxide is likely to be formed.

AlCrN coated samples show considerable oxidation resistance. The outside wear track oxygen surface concentration is at 5%, in contrast to 40–60% for uncoated sample. As at 750°C the coating is worn through, the content of Al, Cr, and N drops significantly, the composite substrate is exposed, and the oxidation occurs, resulting in a massive increase of oxygen. The lubrication of

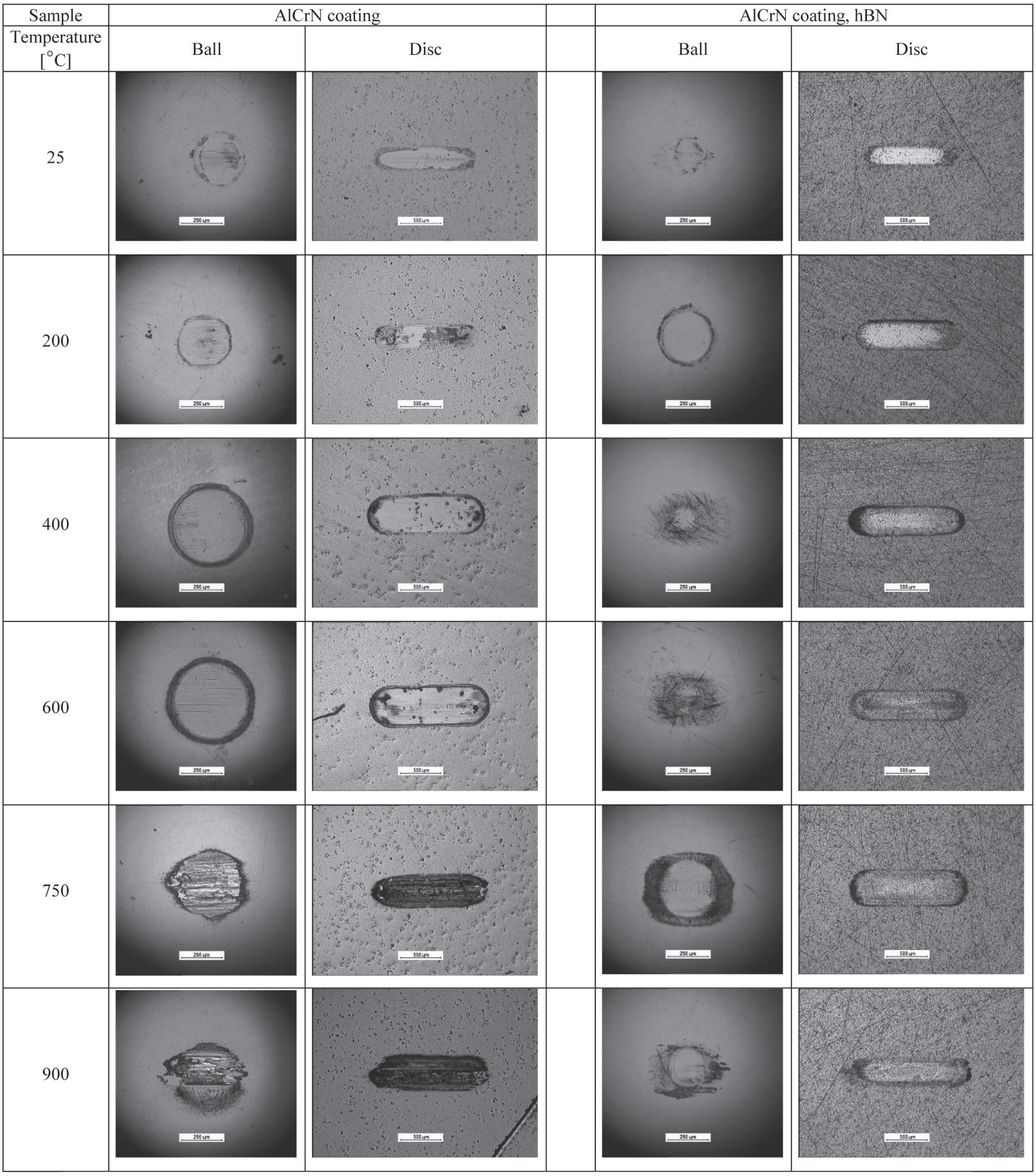

Fig. 7. Microscopy images of coated composite specimens and counter samples wear tested on the SRV tribotester

Rys. 7. Mikroskopowe zdjęcia próbek kompozytu pokrytego powłoką oraz przeciwpróbek po testach na tribotesterze SRV

the coated sample with hBN significantly increases the wear resistance, preventing the substrate prone to oxidation from being revealed and oxidised. The importance of such a form of protection grows with the increase in the applied temperature extending the utility potential of the above-mentioned tribosystem.

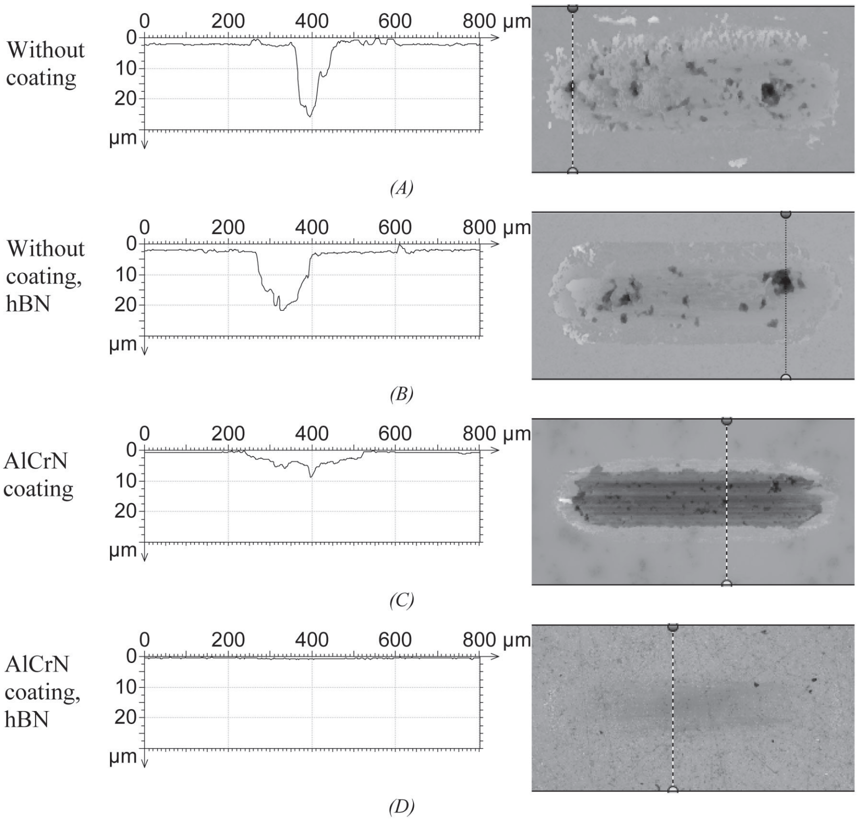

Fig. 8. Selected wear track cross-sections with the indication of their location (after tests at 750°C): (A) TiB_2/Ti composite without coating; (B) TiB_2/Ti composite without coating, with hBN; (C) TiB_2/Ti composite with AlCrN coating; (D) TiB_2/Ti composite with AlCrN coating, with hBN

Rys. 8. Przekroje poprzeczne śladów tarcia oraz ich lokalizacja (po testach w 750°C): (A) kompozyt TiB_2/Ti bez powłoki; (B) kompozyt TiB_2/Ti bez powłoki, z hBN; (C) kompozyt TiB_2/Ti z powłoką AlCrN; (D) kompozyt TiB_2/Ti z powłoką AlCrN, z hBN

Table 5. Chemical composition of uncoated and coated disc samples at 600°C measured by EDS

Tabela 5. Skład chemiczny próbek bez i z powłoką w 600°C zmierzony z wykorzystaniem EDS

Test temperature [°C]	Without coating		Without coating, hBN		AlCrN coating		AlCrN coating, hBN	
600	In the track	Out of the track	In the track	Out of the track	In the track	Out of the track	In the track	Out of the track
Element	Mean [% at.]	Mean [% at.]	Mean [% at.]	Mean [% at.]	Mean [% at.]	Mean [% at.]	Mean [% at.]	Mean [% at.]
O	59.74±1.59	44.94±2.97	39.33±7.16	45.54±1.73	4.73±2.67	0.31±0.62	4.31±4.42	1.92±1.91
B	0.37±0.32	1.16±0.61	2.31±0.12	1.40±0.65	0.76±0.77	0.42±0.43	0.00±0.00	0.32±0.40
C	3.17±0.46	1.61±0.61	2.24±0.30	1.29±0.37	1.30±0.95	1.92±1.29	1.33±1.20	1.22±1.48
N	0.23±0.33	0.77±0.48	0.00±0.00	0.32±0.36	36.80±2.09	40.04±1.08	35.73±2.01	39.65±2.10
Si	0.94±0.43	0.08±0.17	0.07±0.07	0.14±0.16	0.42±0.44	0.04±0.08	0.55±0.25	0.03±0.06
Ti	35.54±2.66	51.44±2.78	56.06±7.35	51.30±1.04	1.94±0.84	1.26±0.18	1.89±0.75	1.28±0.40
Al	–	–	–	–	33.82±0.82	35.28±0.59	35.37±1.95	35.01±0.52
Cr	–	–	–	–	20.23±0.73	20.74±0.72	20.81±1.46	20.57±0.53

Table 6. Chemical composition of uncoated and coated disc samples at 750°C measured by EDS
Tabela 6. Skład chemiczny próbek bez i z powłoką w 750°C zmierzony z wykorzystaniem EDS

Test temperature [°C]	Without coating		Without coating, hBN		AlCrN coating		AlCrN coating, hBN	
750	In the track	Out of the track	In the track	Out of the track	In the track	Out of the track	In the track	Out of the track
Element	Mean [% at.]	Mean [% at.]	Mean [% at.]	Mean [% at.]	Mean [% at.]	Mean [% at.]	Mean [% at.]	Mean [% at.]
O	57.17±5.61	58.53±0.89	56.81±3.43	57.07±2.14	53.66±3.49	2.76±1.45	13.94±3.30	0.54±0.55
B	0.79±0.26	0.46±0.19	0.39±0.11	0.41±0.09	0.48±0.32	0.35±0.70	0.93±0.82	0.30±0.60
C	2.07±0.76	1.29±0.27	1.70±0.58	1.32±0.45	2.40±0.38	1.29±1.39	1.43±0.49	1.20±0.14
N	0.20±0.20	0.00±0.00	0.52±1.03	0.63±0.75	2.21±0.68	39.68±1.26	32.29±2.79	41.74±1.09
Si	1.04±0.40	0.03±0.06	0.55±0.17	0.09±0.10	0.10±0.07	0.04±0.08	0.57±0.17	0.12±0.06
Ti	38.73±6.24	39.70±0.99	40.02±3.77	40.49±1.52	36.84±4.10	1.41±0.18	1.23±0.15	1.50±0.17
Al	–	–	–	–	3.01±0.12	33.98±0.87	31.39±0.47	35.17±0.73
Cr	–	–	–	–	1.30±0.19	20.48±0.96	18.21±0.42	19.42±0.65

SUMMARY

A TiB_2/Ti composite protected by an AlCrN coating and hBN solid state lubricant, rubbing against ceramic Si_3N_4 ball, was investigated in oscillating motion, at the temperature ranging from room temperature up to 900°C. The composite without any coating protection demonstrates stable wear at the temperature up to 400°C. Wear tracks of test at temperatures from 600°C contain a large number of significant grain tearouts. The use of hBN solid lubricant on the composite does not improve wear resistance. Volumetric wear and wear track depth are as high as before. The only benefit is that the number of pits in the wear track is reduced. AlCrN coating deposition ensures stable wear at the temperature up to 600°C and a considerable decrease in the number of pits in the wear trace at higher temperatures. The coating can protect the substrate against the influence of the operating conditions — increased oxidation resistance. Application of hBN solid state lubricant on coating also has influence on wear behaviour. There is no rubbing through the coating when the coating and solid state lubricant hBN are used in the entire test temperature range. It was proved that the combination of the AlCrN coating and hBN decreases the TiB_2/Ti composite wear and improves resistance to oxidation in a wide range of operating temperatures (from 25°C to 900°C). The synergetic effect of an application of the hBN additive and the AlCrN coating was proved by the results obtained in this work.

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