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THE INFLUENCE OF CUTTING FLUID CONTAINING ZINC ASPARTATE ON THE WEAR OF CUTTING TOOLS DURING TURNING

WPŁYW CIECZY OBRÓBKOWEJ Z ASPARAGINIANEM CYNKU NA ZUŻYWANIE NARZĘDZI SKRAWAJĄCYCH PODCZAS TOCZENIA

Key words: cutting fluid, turning, friction, wear, cemented carbides, a-C:H coating.

Abstract: The paper presents the results of tests of the wear of cutting tools following the process of facing with lubrication with cutting fluids. The tests were carried out on a CNC lathe with the use of two cutting fluids: one based on mineral oil and the other containing zinc aspartate. After machining, the tool wear was measured using a stereoscopic inspection microscope. Observation of surface morphology and identification of elements was performed using a scanning electron microscope with a EDS analyser. Measurements of the geometric structure of the surface of turned elements were performed using an optical profilometer. The non-toxic coolant with zinc aspartate used in the tests resulted in the formation of surface layers enriched with zinc compounds, which directly translated into the improvement of technological quality of the workpiece.

Słowa kluczowe: ciecz obróbkowa, toczenie, tarcie, zużycie, węgliki spiekane, powłoka a-C:H.

Streszczenie: W artykule przedstawiono wyniki badań zużycia narzędzi skrawających po procesie toczenia poprzecznego ze smarowaniem cieczami obróbkowymi. Badania wykonano na tokarce sterowanej numerycznie z zastosowaniem dwóch cieczy chłodząco-smarujących na bazie oleju mineralnego oraz zawierającej asparaginian cynku. Po obróbce zmierzono zużycie narzędzi za pomocą stereoskopowego mikroskopu inspekcyjnego. Obserwacje morfologii powierzchni i identyfikację pierwiastków przeprowadzono przy użyciu skaningowego mikroskopu elektronowego z analizatorem EDS. Pomiary struktury geometrycznej powierzchni elementów toczonych wykonano profilometrem optycznym. Zastosowane w badaniach nietoksyczne chłodziwo z asparaginianem cynku spowodowało powstanie warstw wierzchnich wzbogaconych w związki cynku, co bezpośrednio przełożyło się na poprawę jakości technologicznej detalu.

INTRODUCTION

Turning is one of the oldest machining methods commonly used in the industry to produce the desired shape and size of a workpiece. One of the important features is the surface finish of the machined workpiece. The surface roughness of the workpiece is of great importance for the proper selection of machining

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parameters during turning. The most important factors affecting surface roughness include tool geometry, feed and cutting speed, the hardness of the tool and the machined workpiece, the type of coating applied, and the relative vibration of the tool **[L. 1]**. During turning, the majority of mechanical energy is converted into heat, which can cause overheating of the tool and chips and other damages to the machined workpiece. As a result, the actual cutting depth differs from the nominal cutting depth and the accuracy of the machining deteriorates. The exposed contact surfaces are very chemically active and complex physico-chemical processes take place there **[L. 2–5]**. Coolants are usually used during machining operations. Their purpose is to cool and lubricate the tools, thus increasing their service life. In addition, they perform a washing function and have an impact on achieving the proper technological quality of machined workpieces. The use of standard cutting fluids has a negative impact on human health and the surrounding environment **[L. 6–8]**. Therefore, nowadays, the preferred direction of pro-ecological activities is to minimize the harmfulness and increase the biodegradability of cutting fluids **[L. 8–10]**. These activities are aimed at reducing the costs related to waste management and limiting the harmful impact on living organisms and the environment. This can be achieved by the following **[L. 7]**:

1. The modification of the composition of the coolant through the use of
   a) compositions without mineral and synthetic oils, and preference for natural oils,
   b) biodegradable materials, and
   c) tooling materials with increased service life;
2. The minimization of the amount of MQL fluid;
3. Cooling with compressed air, cold gas, or solid coolant; and,
4. Dry machining.

In this article, a non-toxic coolant containing zinc aspartate was used for the tests. It is of plant origin – zinc salt combined with an amino acid of aspartic acid. The selected zinc aspartate can replace the commonly used toxic zinc di-alkyldithiophosphates (ZDDPs), which have good anti-wear and anticorrosive properties. So far, the use of zinc aspartate has been limited only to medical and pharmacological use. The aim of the study was to evaluate the influence of a coolant containing zinc aspartate on the wear of cutting tools and the quality of machined surfaces.

MATERIAL AND METHODS OF TESTS

During facing, the following cemented carbide tools were used: uncoated and with a DLC type a-C:H diamond-like carbon coating. Cemented carbide cutting tools are widely used in machining. Cemented carbide is characterized by good hardness, strength, and resistance to wear and brittleness. The chemical composition of SM25 cemented carbide is presented in **Table 1**. The a-C:H coatings applied, on the other hand, are popular due to their very good tribological properties (low friction, anti-wear properties), chemical stability, and corrosion resistance, high hardness, and thermal stability. The DLC coating was produced by plasma assisted chemical vapour deposition (PACVD). **Table 2** presents its characteristic properties. The Plasma Assisted Chemical Vapour Deposition (PACVD) process is a Chemical Vapour Deposition (CVD) process that is supported by a glow discharge plasma **[L. 11]**. Compared to CVD, the PACVD method is more effective in the initial phase of the nucleation of diamond structures. This process can produce a layer of high hardness, thermal conductivity, chemical inertia, as well as electrical and optical properties similar to diamond **[L. 12]**. In the PACVD process, the pulsed glow discharge occurs at low pressure, resulting in higher internal energy, which allows for a reduction in the process temperature **[L. 13]**.

Table 1. Composition of SM25 cemented carbides
Tabela 1. Skład chemiczny węglików spiekanych SM25

Element	WC	TiC + TaC + NbC	Co
%	69.5	21	9.5

Table 2. The characteristics of a-C:H coating
Tabeli 2. Charakterystyka powłoki a-C:H

Microhardness, HV	Thickness, µm	Coefficient of friction	Temp. of coating process, °C	Max coating work temp., °C	Color
1398	1.02	0.05–0.15	160–300	350	black

During turning the machined material was a 38 mm diameter C45 steel shaft. Its chemical composition is shown in **Table 3.** C45 steel is used for medium duty machine and device components. Products made of this steel can be surface hardened to a hardness of 50–60 HRC.

A cutting fluid based on DEMI demineralised water was used in the tests. The coolant contains alkanolamine borate, biodegradable oligomer based on poly(aspartic acid) (PASP), and demineralised water. The physico-chemical properties of the applied cutting fluid containing zinc aspartate are presented in **Table 4.**

Table 3. Composition of C45 steel
Tabeli 3. Skład chemiczny stali C45

Element	C	Mn	Si	P	S	Cu	Cr	Ni	Mo	W	V	Cu
%	0.42–0.5	0.5–0.8	0.1–0.4	max 0.4	max 0.4	max 0.3	max 0.3	max 0.3	max 0.1	–	–	max 0.3

Table 4. Properties of the cutting fluid containing zinc aspartate
Tabela 4. Właściwości cieczy chłodząco-smarującej zawierającej asparaginian cynku

Colour	Smell	pH value	Density, g/cm^3	Solubility in water
from arrange to red	specific	9.5	1.25	soluble

The cutting fluid containing zinc aspartate was compared with the commercial cutting fluid. It contains mainly mineral oil and ethoxylated alcohols, boric acid, dicyclohexylamine, carbamate, and benzoisothiazole. It is used from general to heavy-duty machining of aluminium, steel, cast iron, non-ferrous metals, aluminium alloys, brass, and copper. The basic parameters of the cutting fluid are shown in **Table 5.**

Table 5. Properties of the cutting fluid containing base oil
Tabela 5. Właściwości cieczy chłodząco-smarującej na bazie oleju mineralnego

Colour	Smell	Mineral oil content	pH value	Density, g/cm^3	Solubility in water
yellow-brown	like mineral oil	56%	9.1	0.92–0.96	soluble

Using a JEOL JSM-7100F scanning electron microscope with a EDS microanalyser, the elements forming the cutting tools and coatings were observed and identified.

The coating thickness was measured using a compact Calotest CATc module. The test consisted of the abrasion of the coating by means of a ball moving at a constant speed. A polishing suspension was applied at the point of contact between the sample and the ball. The abrasion diameter was measured using an optical microscope.

A Leica DCM8 confocal microscope with interferometry mode was used to measure the geometric structure of machined workpieces. The results obtained were analysed using the program LeicaMap 7.

Facing was carried out on the CTX 310 ECO CNC lathe. Facing was performed with the use of two cutting fluids.

RESULTS AND DISCUSSIONS

The JEOL JSM-7100F electron microscope with the EDS analyser was used for the observation of surface morphology and the analysis of the elemental composition in the micro-area of the cemented carbide cutting tool **(Fig. 1**). **Table 6** presents the results of the point analysis of the elements composing the cemented carbide insert.

The presented surface microstructure of the cemented carbide tool **(Fig. 1a**) is indicative of a phase structure, where lighter and darker areas were observed. The point analysis of the chemical composition of the cutting tool in the light area (Point 1) showed the content of tungsten, carbon, and cobalt **(Fig. 1b**). In the darker area (**Fig. 1c**), (Point 2), the following were recorded: tantalum, tungsten, titanium, niobium, cobalt, and carbon; therefore, carbides of tungsten, titanium, tantalum, niobium, and cobalt are present in this phase.

Figure 2 presents a photograph of the surface morphology and an analysis of the composition of the elements in the micro-area of the cemented carbide cutting tool with a-C:H coating applied, and **Table 7** shows their chemical composition. The a-C:H coating was characterized by a more homogeneous surface structure than the cemented carbide insert without coating, although lighter areas were also observed (**Fig. 2a**). The point analyses of the chemical composition of the a-C: H coating in a light area (**Fig. 2b**) indicate the presence of elements such as tungsten, carbon, titanium, and chromium, which comes from the interlayer improving the adhesion of the coating to the substrate. However, in the dark area (**Fig. 2c**), only tungsten, carbon, and chromium were recorded.

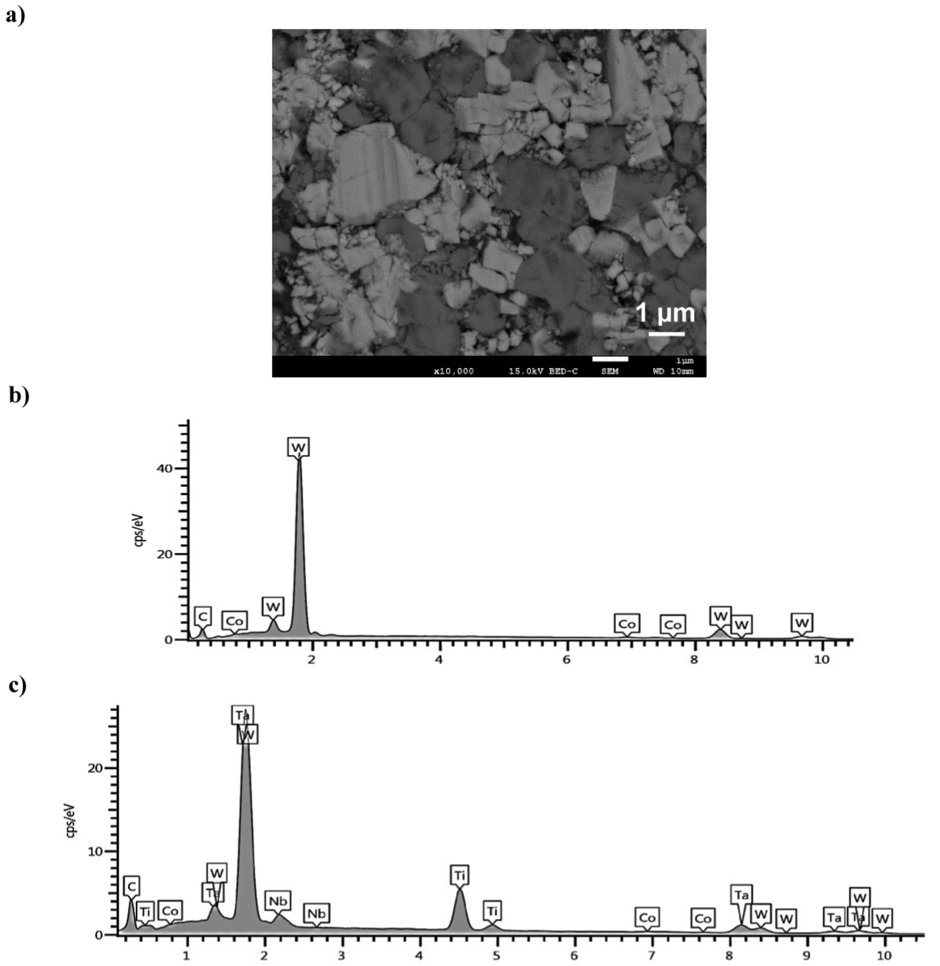


Fig. 1. SEM: (a) view of the cemented carbide insert and the X-ray spectrum together with the chemical composition in the micro-area: (b) Point 1, (c) Point 2

Rys. 1. SEM: a) widok płytki z węglików spiekanych oraz spektrum promieniowania rentgenowskiego wraz ze składem chemicznym w mikroobszarze: b) punkt 1, c) punkt 2

Table 6. Composition of cemented carbides tool

Tabela 6. Skład chemiczny płytki z węglików spiekanych

Element / %	Point 1	Point 2
W	95.11	32.88
C	3.81	6.16
Ta	–	38.93
Ti	–	15.75
Nb	–	4.05
Co	1.08	2.23

A CATc calotester and optical microscope were used to determine the thickness of a diamond-like coating. The microscope images together with the a-C: H coating thickness measurements are shown in **Fig. 3**. The measured thickness of the a-C:H coating was 1.02 µm.

The turning process, the most important parameters of which are listed in **Table 8**, was carried out on a CNC lathe. Three tests of facing were made for each of the analysed materials. Each test consisted of 100 passages. After each test, the tool and the machined material were examined using a microscope. The wear of the cutting tools was shown using a SX80 stereoscopic inspection microscope **(Fig. 4)**. **Figures 5** and **6** present the topography and surface profiles of the machined workpieces.

When comparing the obtained graphs of tool wear, it was observed that lower values of the average width of the band of abrasive wear on the contact surface (VB_B) and the maximum width of the band of abrasive wear on the contact surface (VB_Bmax) were obtained after turning using cemented carbide tools with the use of mineral oil-based coolant. Taking into account the VB_Bmax parameters describing the wear of uncoated cemented carbide tools, results are the same for both tested coolants.

a)

b)

c)

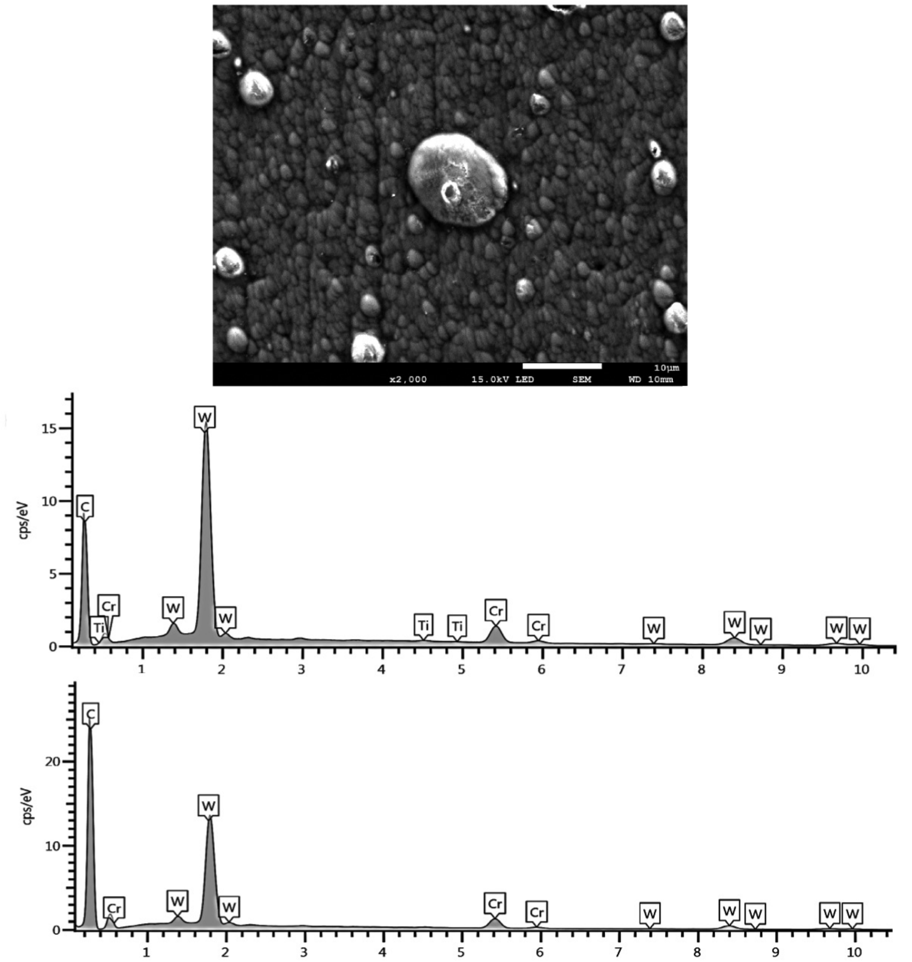


Fig. 2. SEM: (a) view of the a-C:H coated cemented carbide insert and the X-ray spectrum together with the chemical composition in the micro-area: (b) Point 1, (c) Point 2, (d) Point 3

Rys. 2. SEM: a) widok płytki z węglików spiekanych z powłoką a-C:H oraz spektrum promieniowania rentgenowskiego wraz ze składem chemicznym w mikroobszarze: (b) punkt 1, (c) punkt 2, (d) punkt 3

Table 7. Composition of cemented carbides with a-C:H coating tool

Tabela 7. Skład chemiczny płytki z węglików spiekanych z powłoką a-C:H

Element / %	Point 1	Point 2
W	39.66	35.07
C	53.86	58.88
Cr	6.02	6.05
Ti	0.28	-

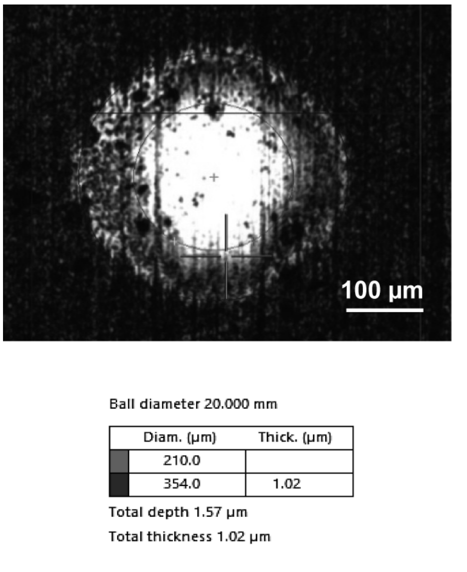


Fig. 3. View of abrasion after the measurement of the a-C:H coating thickness

Rys. 3. Widok wytarcia po pomiarze grubości powłoki a-C:H

The surface profiles obtained indicate that the lowest elevations and the shallowest recesses were formed on the element after turning using an a-C:H coated cemented carbide tool with a cutting fluid containing zinc aspartate. After machining using tools without and with a-C: H coating, every tool passage (feed rate

0.2 mm) is clearly visible. After turning using a cemented carbide tool with a-C:H coating without and with a-C:H coating with a coolant containing zinc aspartate few elevations were observed that could have been formed when the particles of the workpiece material transferred with the chip adhered to the workpiece.

Table 9 presents the parameters of the surface topography of the surface of machined materials produced after turning with cutting fluids.

Table 8. Parameters of turning process
Tabela 8. Parametry toczenia

Rotation speed, n, m/min	Turning diameter, d, mm	Cutting speed, v_c, m/min	Feed rate, f, mm/rate	Cutting depth ap, mm
1 257÷ 3 000	38÷15.92	150	0.2	0.5
3 000	15.92÷0	150÷0	0.2	0.5

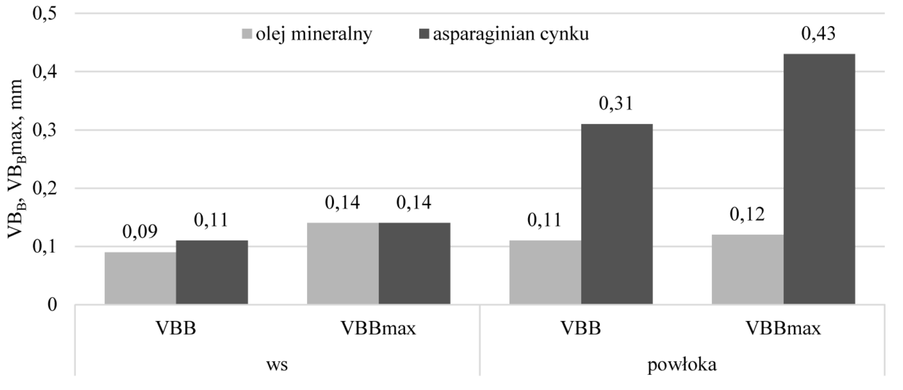


Fig. 4. Measurement of the wear of cemented carbide tools (cc) with and without a-C:H coating after turning with cutting fluids
Rys. 4. Pomiary zużycia narzędzi z węglików spiekanych bez i z powłoką a-C:H po toczeniu z chłodziwami

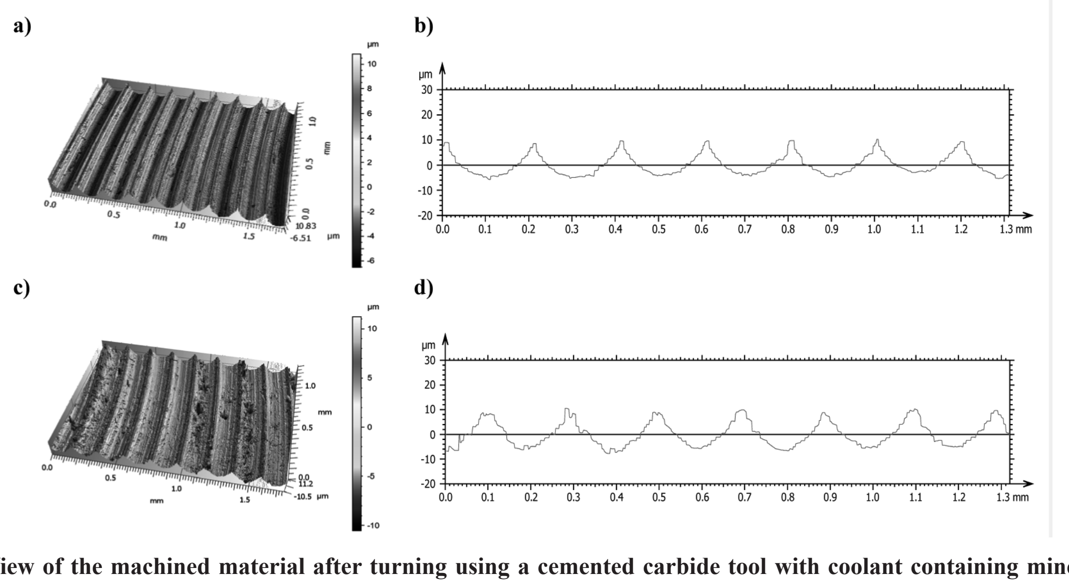


Fig. 5. View of the machined material after turning using a cemented carbide tool with coolant containing mineral oil: (a) isometric image, (b) primary profile and with a cutting fluid containing zinc aspartate: (c) isometric picture, (d) primary profile
Rys. 5. Widok materiału obrabianego po toczeniu narzędziem z węglików spiekanych z chłodziwem z olejem mineralnym: a) obraz izometryczny, b) profil pierwotny oraz z chłodziwem z asparaginianem cynku: c) obraz izometryczny, d) profil pierwotny

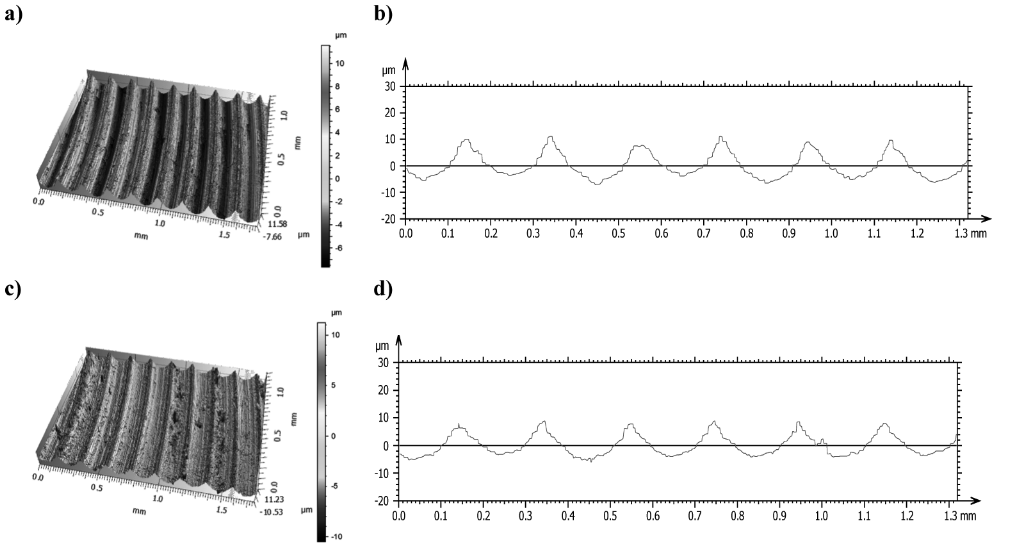


Fig. 6. View of the machined material after turning using a cemented carbide tool with a-C:H coating with a coolant containing mineral oil: (a) isometric image, (b) primary profile and with a cutting fluid containing zinc aspartate: (c) isometric picture, (d) primary profile

Rys. 6. Widok materiału obrabianego po toczeniu narzędziem z węglików spiekanych z węglików spiekanych z powłoką a-C:H z chłodziwem z olejem mineralnym: a) obraz izometryczny, b) profil pierwotny oraz z chłodziwem z asparaginianem cynku: c) obraz izometryczny, d) profil pierwotny

Table 9. Surface texture parameters for workpiece after face turning

Tabela 9. Parametry struktury geometrycznej powierzchni materiałów obrobionych po toczeniu czołowym

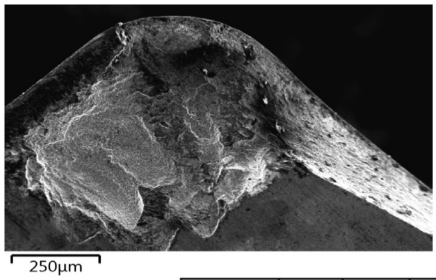
Cemented carbides cutting tool – type of cutting fluid	Surface texture parameters					
	Sq	Sp	Sv	Sz	Ssk	Sku
	µm	µm	µm	µm	–	–
Without coating – cutting fluid with mineral oil	4.01	10.71	6.63	17.34	0.80	2.61
Without coating – cutting fluid with zinc aspartate	4.88	15.17	16.91	32.08	0.51	2.33
With a-C:H coating – cutting fluid with mineral oil	4.67	11.58	7.66	19.24	0.62	2.17
With a-C:H coating – cutting fluid with zinc aspartate	3.80	11.20	10.50	21.80	0.56	2.23

The lowest value of Sq parameters were recorded for cemented carbide tools with a-C:H coating applied after turning with a coolant containing zinc aspartate, which indicates that the surface of machined workpieces was smooth. The lowest values of Sp, Sv, and Sz parameters were observed after turning using cemented carbide tools with a coolant based on mineral oil. Ssk parameters, which are the surface skewness (asymmetry) coefficients, in all cases, have positive values, which indicate the occurrence of elevations with sharpened spikes. Whereas, the Sku parameter, which is the surface slope coefficient (kurtosis), is a measure of the smoothness of the distribution curve of ordinates, which is also called “the coefficient of concentration.” For the normal ordinates distribution, the Sku = 3. The obtained values of kurtosis indicate that the ordinate distributions for both cutting tools are similar to the normal distribution.

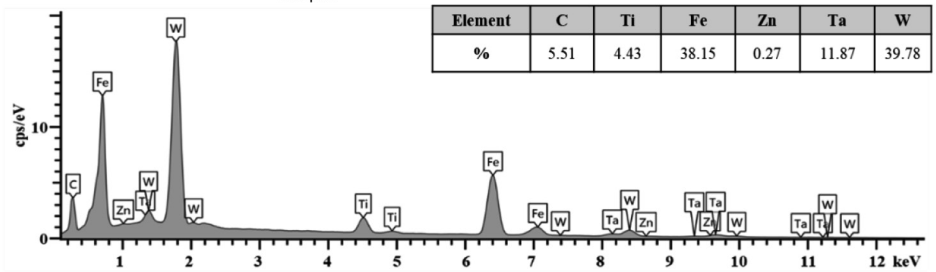
Figures 7 and **8** present SEM images of traces of tool wear after machining with a coolant containing zinc aspartate and qualitative (point analysis of the elemental composition) analysis with the use of a JEOL JSM 7100F scanning microscope. The tests were carried out in order to check whether there were any layers of zinc compounds on the cutting tool.

On tools made of cemented carbides without and with a-C:H coating applied at selected points on the build-up after turning with the use of coolant, in addition to the elements coming from the tool material (tungsten, titanium, cobalt, chromium), additional elements included in the composition of the machined workpiece, i.e. iron and zinc coming from the cutting fluid, were observed. The presence of iron indicated the transfer of material from the machined workpiece. Thus, the adhesion of the tool material to the workpiece material took place. Zinc atoms were registered, which may prove the formation of anti-wear layers of zinc compounds. There were more zinc atoms on the tool with a-C:H coating than on the tool without the coating.

a)



b)

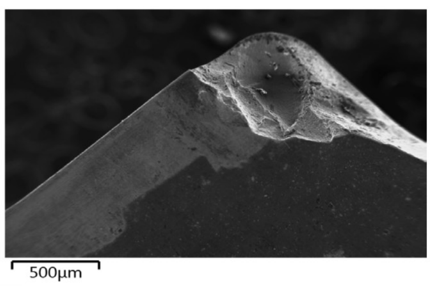


Element	C	Ti	Fe	Zn	Ta	W
%	5.51	4.43	38.15	0.27	11.87	39.78

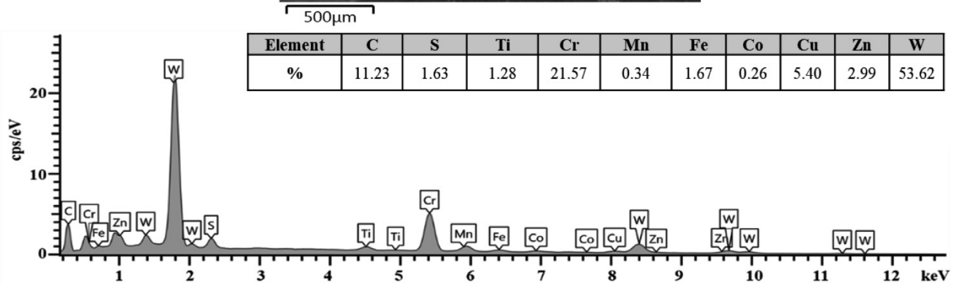
Fig. 7. SEM analysis of the tool wear made of cemented carbides after turning with cutting fluid containing zinc aspartate: (a) image of the wear track and (b) X-ray energy spectrum

Rys. 7. SEM: a) widok zużycia narzędzia z węgików spiekanych po toczeniu z chłodziwem z asparaginianem cynku, b) analiza punktowa pierwiastków

a)



b)



Element	C	S	Ti	Cr	Mn	Fe	Co	Cu	Zn	W
%	11.23	1.63	1.28	21.57	0.34	1.67	0.26	5.40	2.99	53.62

Fig. 8. SEM analysis of the tool wear made of cemented carbides with a-C:H coating after turning with cutting fluid containing zinc aspartate: (a) image of the wear track and (b) X-ray energy spectrum

Rys. 8. SEM: a) widok zużycia narzędzia z węglików spiekanych z powłoką a-C:H po toczeniu z chłodziwem z asparaginianem cynku chłodziwem z olejem mineralnym, b) analiza punktowa pierwiastków

CONCLUSIONS

The tests carried out in the study are in line with current trends in waste management and ecological activities. The pro-ecological fluid containing zinc aspartate used in the tests may influence the minimization of costs connected with waste management.

After face turning using cemented carbide tools with both cutting fluids, the same $VB_B max$ values, i.e. the maximum band of abrasive wear on the contact surface, were obtained. Therefore, the use of a coolant with zinc aspartate allows the elimination of toxic substances from the cutting fluids, while simultaneously preserving the service life of cutting tools. On the other hand, a better technological quality of the surface layer of the machined workpiece was obtained using a mineral oil-based coolant. However, after turning using cemented carbide tools with a-C:H coating applied with a coolant containing zinc aspartate, the values of parameters describing tool wear were more than 3 times higher. In turn, after machining with cemented carbide tools with a-C:H coating applied, a better technological quality of the surface layer of the machined workpiece was obtained than after turning with a mineral oil-based coolant.

After turning using cemented carbide tools with a-C:H coating, after turning with a coolant containing zinc aspartate, anti-wear surface layers made of zinc compounds appeared.

The non-toxic coolant containing zinc aspartate works better with cemented carbide tools.

To sum up, the use of a non-toxic coolant is related to the choice of either a better technological quality of the surface layer of the machined workpiece and higher wear of the a-C:H coated tool, or the similar wear of the cemented carbide tool, but a worse technological quality of the surface layer of the machined workpiece.

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