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Article

Tribological behaviour of K340 steel PVD coated with CrAlSiN versus popular tool steel grades

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Abstract: The tribological performance of metalwork steel tools is of vital importance in both cold and hot working processes. One solution for improving metal tool life is the application of coatings. This paper investigates the effect of CrAlSiN thin-film PVD-deposition on the tribological behaviour of tool steel K340. The sliding wear performance of the coated K340 steel is analysed in relation to both the uncoated K340 steel and a range of tool steels dedicated to hot- and cold-working, such as X155CrVMo12-1, X37CrMoV5-1, X40CrMoV5-1, 40CrMnMo7 and 90MnCrV8. The investigated tool steels were heat-treated, while K340 was subjected to thermochemical treatment and then coated with a CrAlSiN hard film (K340/CrAlSiN). The hardness, chemical composition, phase structure and microstructure of steels K340 and K340/CrAlSiN are examined. Tribological tests were conducted using the ball-on-disc tester in compliance with the ASTM G99 standard. The tests were performed under dry unidirectional sliding conditions, using an Al_2O_3 ball as a counterbody. The wear factor and coefficient of friction are estimated and analysed with respect to hardness and alloying composition of the materials under study. SEM observations are made to identify the sliding wear mechanisms of the analysed tool steels and PVD-coated K340 steel. In contrast to the harsh abrasive-adhesive wear mechanism observed for uncoated tool steels, the abrasive wear dominates in case of the AlCrSiN. The deposited thin film effectively prevents the K304 substrate from harsh wear severe degradation. Moreover, thanks to the deposited coating, the K304/CrAlSiN sample has a COF of 0.529 and a wear factor of $K = 5.68 \times 10^{-7}\ \mathrm{m^3\,N^{-1}\,m^{-1}}$, while the COF of the reference tool steels ranges from 0.702 to 0.885 and their wear factor ranges from $1.68 \times 10^{-5}\ \mathrm{m^3\,N^{-1}\,m^{-1}}$ to $3.67 \times 10^{-5}\ \mathrm{m^3\,N^{-1}\,m^{-1}}$. The CrAlSiN deposition reduces the wear of the K340 steel and improves its sliding properties, which makes it a promising method for prolonging the service life of metalwork tools.

Keywords: cold/hot-work steel; sliding; friction; wear testing; XRD analysis; wear mechanism; hardness; heat treatment; thin film; abrasion

1. Introduction

Despite the development of new technologies such as sintered carbides and ceramic materials, tool steels are still widely used in the industry. This results from the high quality, wide availability and fair price of these materials. To obtain an effective and durable tool, it is necessary to employ a suitable heat treatment or surface layer modification technology or to deposit a coating with the required properties. Another important aspect is to select a steel grade that exhibits properties meeting the requirements for a given tool application and maximizes the tool durability during the cold- or

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hot-working [1–3]. Still, studies are conducted to develop new materials [4] and methods for shaping microstructure, particularly surface layer, of tool steels [5].

Tool steels are characterized by high hardness, resistance to abrasion and deformation, as well as the ability to withstand elevated temperatures. These characteristics can be obtained by increasing the carbon content and the application of appropriate heat treatment (low-responsibility tools) as well as the use of high alloy steel grades and heat treatment (responsible tools), or by the application of appropriate coatings [6,7].

A key requirement for cold-work carbon steels is their high hardness and resistance to abrasion. If high surface pressures are generated during tool operation, it is necessary to increase the resistance of core and surface layer or apply the coating. The surface layer resistance must be high enough to carry the tool operation load and stresses. This can be obtained by enriching steel with alloying elements. The most popular grades of tool steel contain alloying components showing a close affinity with carbon, i.e., Cr, Mo, W and V therefore, in the steel microstructure the hard phases can be formed. Such microstructure of steel leads to increased resistance to abrasion. The use of alloying elements in appropriate proportions makes it possible to optimize strength and abrasive properties of tools [5,8].

A current trend is to improve the tribological performance of cold work tools. Different attempts are made to this end, including Zr, Ti nitriding [9], for which the smallest wear rate was obtained at the atomic percentage of 46% nitrogen. The authors of [10], heat treated material in atmosphere of nitrogen after PVD coating and found that the CrAlSiN film was able to retain the initial structure after annealing up to 800 °C. The wear resistance of a PVD-TiAlN-coated tool was found superior compared to that of a FSP (fine shot peening) modified surface tool [11]. Following the results, many authors use PVD TiN-based thin films to reduce wear factor and mitigate the degradation processes of metallic substrates [12,13].

Some researchers attempt to increase abrasion resistance by depositing different combinations of coatings [9,14,15] (also known as nano-layers [16]), including those with only slightly different chemical composition [17–19] or chemical-composition gradient [20,21]. The highest improvement of the double layered CrAlSiN + CrN/C coating was nearly three times more reliable than that of the tool coated with a single CrAlSiN layer [22]. According to [23]the elastic modulus is a linear function of hardness (in GPa units) of nitride coatings, but the elements which do not create nitrides (Co, Cu, Fe, Ni, Mn) are inclined to form a metallic phase, which can disturb the crystalline structure and lead to amorphization.

Nitriding and/or PVD coating are popular surface treatment processes for hot-work tool steels. Each process helps increase the hardness of a workpiece surface up to at least 1200 HV. Therefore, hardness of PVD deposited nitride binary coating systems does not exceed 30 GPa [24] which can be achieved by deposition of complex coating systems. The high functional properties of nitride coatings deposited on alloy steels result from the fact that such coatings remain stable at elevated temperature [25]. Given that this treatment is characterized by a lower temperature than the polymorphic transition temperature and a longer time, PVD coatings can be deposited after quenching, sometimes together with tempering. Nitride PVD coatings increase the potential applications for steels because -– apart from high resistance to surface stresses/loads and abrasion -– they also ensure resistance to the harsh environment. The deposition of the Al-rich AlTiN thin films successfully prevents the steel substrate from the sliding wear and cavitation erosion [26]; while the silicon enrichment of the CrAlN coatings increases hardness by approx. 34% [27] and salt water resistance [28]. The resistance to oxidation at elevated temperatures induces the formation of Al, Cr and Si oxides that remain stable up to 700 °C [27]. The CrAlSiN coating deposited by unbalanced magnetron sputtering exhibits better tribological and mechanical properties up to 700 °C than the CrAlN coating, according to nanoindentation and tribological tests [29,30]. Also, the average wear factor (about 0.08) of the CrAlSiN coating was lower at high temperature [31]. CrAlSiN hard coatings with a CW structure, where Al substitutes Cr in the CrN-based structure, are used for manufacturing dies, moulds and cutting tools due to their properties, especially wear and oxidation resistance [19,32,33].

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The literature review demonstrates that the K340 steel has not been exhaustively tested. There is practically no description of its tribological performance in the literature. Compared to tool steels, this steel grade should offer many advantages, such as good machinability and small dimensional changes during heat treatment [34]. Therefore, this research investigates the effect of AlCrSiN PVD coating deposition on the ambient temperature tribological performance of steel K340, as this problem has not been yet well documented in the literature. Additionally, the current study presents the original comparison of the sliding wear results obtained for K340 and a set of popular tool steels designated to cold- and hot-working. Moreover, dry sliding wear behaviour and damage mechanisms of the K340 coated by CrAlSiN thin film were investigated in relation to the reference tool steels. Results presented in this study may prove useful for fabrication and prolonging the service life of cold-working tools.

2. Materials and Methods

Table 1. Technological parameters of heat- and thermochemical treatment of the K340/CrAlSiN samples

	Stage chronologically	Time, min	Stage temperature, °C		
			at the beginning	continuous	at the end
Austenitization	preheating	210	ambient		700
	soaking	180		700	
	reheating	60	700		870
	soaking	180		870	
	reheating	45	870		1030
	soaking	90		1030	
	N_2 quenching		1030		ambient
Tempering	preheating	120	ambient		505
	tempering I	240		505	
	air cooling		505		ambient
	preheating	120	ambient		505
	tempering II	210		505	
	air cooling		505		ambient
	preheating	120	ambient		505
	tempering III	210		505	
	air cooling		505		ambient
	preheating	120	ambient		510
	tempering IV	240		510	
	air cooling		510		ambient
Nitriding	preheating	30	ambient		450
	soaking	240		450	
	reheating	30	450		540
	nitriding	2400		540	
	air cooling		540		ambient
	PVD deposition	300		445	

The study was focused on the competitive analysis of the tribological performance of K340 steel with the set of reference tool steels. The exact object of this study were two types of the K340-based samples marked as fallows: K340 (after heat treatment) and K340/CrAlSiN (after heat- and thermochemical treatment). K340 grade of steel that is used for cold-work tool applications. Its average hardness, measured according to [35], in as-received condition was 225 HBW. The K340 samples processing was initiated with austenitization in the vacuum furnace and subsequent quenched with N_2 (5 bar) string, see Table 1. The final obtained hardness of the samples was equal to 62 HRC [36]. After quenching, the K340 steel samples were subjected to four tempering processes. Three of them involved heating the samples for 120 min to the temperature of 505 °C and soaking for 210 min. In the final tempering process, the samples were heated up to 510 °C for 120 min and soaked for 240 min. Following every tempering process, the material was air-cooled.

One batch of the K340 steel samples was prepared for further testing. The other batch was first heat-treated and then subjected to additional treatment (nitriding and PVD). Accordingly to the aim of the work, the tribological behaviour of K340 and K340/CrAlSiN samples were analysed with relation to the hardness and wear properties of popular hot- and cold-work tool steels. For comparison purposes, two hot-work tool steel grades (X37CrMoV5-1 and X40CrMoV5-1) and three grades of cold-work steel were selected. Standard chemical compositions of the tested tool steels are given in Table 2. Data in the table are shown in a chromium content descending order. All analysed steel samples were subjected to quenching and tempering heat treatment. Additionally, the chemical analysis of the K340 steel was performed with the Magellan Q8 spark emission spectrometer (Bruker, Germany); the Fe100 test channel was used to complete five (5) analyses (sparking sequences) for every sample.

Table 2. Chemical composition of the tested K340 steel and and the set of reference tool steels

Steel grade	Content of element (Fe – balance), wt. %									
	C	Si	Mn	Cr	Mo	Ni	V	W	S	P
X155CrVMo12-1	1.525	0.350	0.400	12.000	1.000		0.850		0.030	0.030
K340	1.100	0.900	0.400	8.300	2.100		0.500			
K340*	1.111	0.767	0.406	8.297	1.961	0.329	0.530	0.071	0.002	0.021
X40CrMoV5-1	0.385	1.000	0.375	5.150	1.350		2.000		0.030	0.020
X37CrMoV5-1	0.370	1.000	0.375	5.150	1.300		0.400		0.030	0.020
40CrMnMo7	0.400	0.300	1.450	1.950	0.200				0.030	0.030
90MnCrV8	0.900	0.250	2.000	0.350			0.125		0.030	0.030

* – results of spectrometer analysis

The samples used for hardness, chemical composition and tribological testing were made as discs with a diameter of ⌀25 mm and a thickness of 6 mm. The steel discs were subjected to grinding with water abrasive papers with the grain size of 200, 400, 600 and 1200, respectively. After grinding, the samples were mechanically polished with a 3 µm diamond particle suspension and 0.05 µm oxide particle suspension, washed in acetone and dried. Microstructures of the K340 and K340/CrAlSiN samples were examined by bright-field optical microscopy using Nikon MA200 (Nikon Corporation, Tokyo, Japan) and scanning electron microscopy (SEM-EDS, Phenom World ProX, Phenom World, Waltham, MA, USA). The chemical composition of CrAlSiN thin film was analysed in the samples cross-section using SEM-EDS method.

Phase composition of the samples was identified with the use of the ARL XTRa X-ray diffractometer from Thermo Fisher. A filtered copper lamp (CuKα, $\lambda = 0.1542$ nm), with a voltage of 40 kV, range $2\theta = 20° - 120°$ and step size 0.02°/3 s was used. Phase composition was determined using the PDF developed and issued by the ICDD.

Hardness tests were conducted using the Vickers FM-700 microhardness meter with an automatic ARS 900 system (Future-Tech Corp.), according to standard [37]. To ensure statistical accuracy, at least 7 indentations were made in random locations. After that, the Rockwell hardness was recalculated into the Vickers scale in acompliance with the ISO 18265 standard [38]. The deposited nitride film hardness was tested on the top of AlCrSiN film surface using an Ultra Nanoindentation Tester (Anton Paar GmbH, Ostfildern, Germany), in compliance with the procedures described in [39]. The thin film nanohardness was measured for comparison with the surface macro hardness mesured with Vickers hardness tester.

Wear tests were performed on a "ball-on-disc" tribotester manufactured by CSM Instruments. Al_2O_3 balls (manufactured by CSM Instruments) with a diameter of 6 mm were used as counterbodies. The total test distance used for measuring COF variation for a single sample was set equal to 1000 m. The tests were performed under conditions described in Table 3.

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Table 3. Parameters of tribological tests

Parameter	Load	Linear speed	Rotational diameter	Temperature	Humidity
Unit	N	$cm\,s^{-1}$	mm	°C	%
Value	10	10	6	22	30

Wear was measured as the reduction of material volume in the form of a wear track resulting from the specimen–counterbody interaction. The Dektak 150 profile contact tester from Veeco Instruments was used to measure the wear profile surface area along the specimen circumference (in 12 locations). The wear volume was determined as the average value wear profile areas and the circumference of a wear track circle created during the ball-on-disc test. After that, the wear factor K was determined by Equation (1) considering the wear volume, force and sliding distance in the test:

$$K = \frac{Wear\ volume}{Applied\ force \times Sliding\ distance} \qquad mm^3\,N^{-1}\,m^{-1} \tag{1}$$

After the tribological tests, in order to investigate the sliding wear mechanism, the samples wear tracks were examined using electron scanning microscope.

3. Results and discussion

3.1. Materials properties

Results of the hardness tests are given in Table 4. Data in the table are ordered by Vickers hardness. Following the heat treatment, the surface layer hardness of steel K340 is considerably higher (by at least 78 HV) than that of other tested steel grades. As a result of the applied heat treating processes, i.e., nitriding and CrAlSiN coating deposition, the hardness of this material (samples denoted as K340/CrAlSiN) increased again by almost two times to over 1300 HV. Regarding the five other tested grades of steel, their post-treatment mean hardness ranges between 518 HV and 669 HV. These five steel grades include two heat-treated hot-work steels with a hardness of approx. 550 HV. Moreover, the CrAlSiN hard film hardness was estimated with nanohardness tester, equals 29.1±8.9 GPa which is superior hardness to the results given by the Vickers tester. Also estimated nano-hardness is in the range of the value reported by the literature [40] and it conforms with the hardness reported for other nitride hard-films likewise TiAlN, AlTiN, and AlCrN [30,41].

Table 4. Treatment parameters and ovelall surface hardness of the tested materials

Steel grade	Work	Processing temperature, °C			Hardness			
		Austenitizing	Tempering	PVD	HRC	SD	HV	SD
K340/CrAlSiN	cold	1030	505÷510	445			1314	91.9
K340	cold	1030	505÷510		62.0	1.21	747	25.3
90MnCrV8	cold	800	270		58.8	0.55	669	12.3
X155CrVMo12-1	cold	1020	270		57.0	0.23	631	4.7
X40CrMoV5-1	hot	1000	300		53.5	0.86	569	14.1
X37CrMoV5-1	hot	1020	270		51.3	0.94	533	15.4
40CrMnMo7	cold	800	270		50.3	0.83	518	12.2

Microstructure of the heat-treated K340 steel is shown in Figure 1. Despite the presence of spheroidized carbides, martensite lathes are visible in the structure of the K340 sample. The diffusion nitride layer on the K340 steel sample is visible to a depth of about 100 µm. One can see a two-phase structure with the sorbite matrix and brighter carbides (Figure 1a). Also, two types of carbides can be distinguished. One is characterized by elongated grains of ferrite-based solid solution that are shredded relative to the direction of plastic deformation which took place during steel fabrication.

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The other contains more uniformly distributed fine precipitations of alloy carbides (up to a few µm in size) that, according to the literature of the subject [42], are typically generated during tempering. The microstructure in the centre of the sample is similar to the structure shown in Figure 1b. Moreover, one can observe a visible nitride layer with a sharp boundary at the average depth of about 100 µm below the surface.

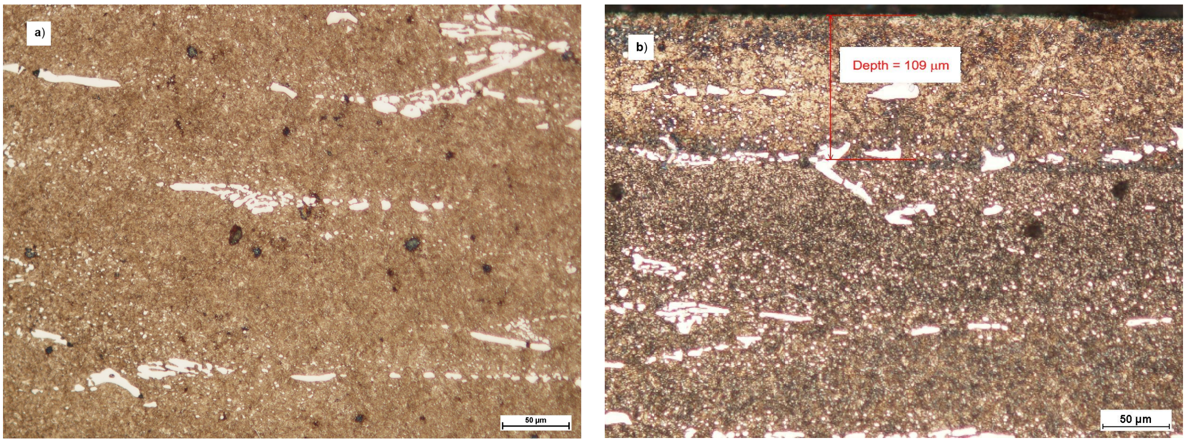

Figure 1. Microstructure of the tested K340 steel samples: **a**) core-area and **b**) nitrided surface layer

Figure 2 shows the SEM image of the CrAlSiN coating cross-section on the nitride layer in the K340/CrAlSiN sample. The thickness of PVD coating on K340/CrAlSiN sample varies from 2.8 µm to 3.6 µm. Table 5 gives the average chemical composition of the deposited CrAlSiN coating obtained from EDS measurements for 7 spots. Data are ordered by atomic concentration of particular elements. It can be seen that the coating has more Al atoms than Cr. Nevertheless, the coating has an atomic stoichiometry of $Cr_{0.37}Al_{0.26}Si_{0.03}N$ which is comparable with data reported in the literature [43–45].

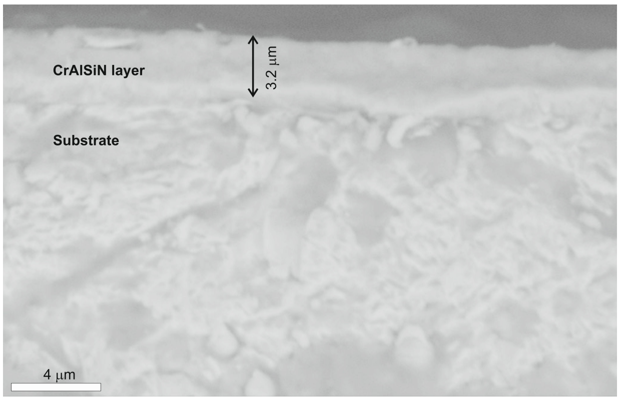

Figure 2. SEM image of K340/CrAlSiN sample

Table 5. Average contents of elements in the analysed CrAlSiN layer

Symbol	Concentration, at. %	SD, at. %
N	56.99	4.09
Al	23.19	1.30
Cr	17.25	4.05
Si	2.57	0.14

X-ray diffraction was employed to analyse the phase content of steel K340 in as-received condition and after CrAlSiN coating deposition by PVD. Obtained results are given in Figure 3. The sample of K340 in as-received condition contains a ferrite phase (ICDD 04-002-1833). Following the coating deposition, two phases can be distinguished: Cr(Al)N (ICDD 04-021-7700) and CrN0.9 (ICDD 01-083-5613). The peaks of the CrN and AlN phases nearly overlap, being pairs with the identical lattice planes (Miller indices), and are thus hard to differentiate. Nevertheless, the phase structure of the nitride layer significantly differs from that of the substrate.

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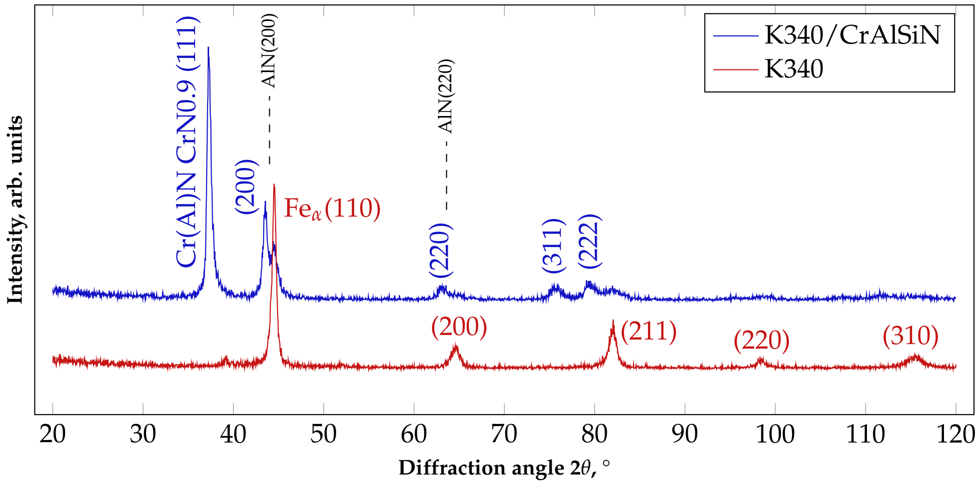

Figure 3. XRD spectra of the K340 sample in as-received condition and after CrAlSiN coating deposition

3.2. Wear behaviour

Obtained average coefficients of friction are given in Table 6 and plotted in relation to distance in Figure 4. For most tested steels, the average COF ranges between 0.702 and 0.883. Regarding the cold-work steels, the highest COF is achieved by the X155CrVMo12-1 steel grade that is characterized by the highest carbon and chromium content out of the analysed materials. As for the other tested cold-work steel grades, the COF variations are not statistically significant considering the standard deviation. It should, however, be pointed out that the lowest average COF (with narrow range variations over distance) is obtained for the sample of K340/CrAlSiN steel. Deposition of the CrAlSiN thin film onto the nitrided surface layer of K340 steel effectively decrease the CoF to the value of 0.529.

Table 6. Friction coefficients of the tested samples

Sample steel	Work	Average friction coefficient μ	Standard deviation
X37CrMoV5-1	hot	0.885	0.057
X155CrVMo12-1	cold	0.883	0.066
X40CrMoV5-1	hot	0.807	0.064
K340	cold	0.739	0.089
40CrMnMo7	cold	0.707	0.044
90MnCrV8	cold	0.702	0.052
K340/CrAlSiN	cold	0.529	0.047

During the tribological test, the COF of most samples is stable and the standard deviation is lower by at least one order of magnitude than the average value (Table 6). The highest COF variation (SD amounting to 12% of the average value) is observed for the sample of quenched and tempered K340. The COF value of this steel grade rapidly increases after approx. 500 m of sliding distance (Figure 4). This unstable behaviour pattern of the COF may be explained by the microstructure of steel K340, in particular the carbide banding. The numerous and relatively large carbides (Figure 1a) constitute a natural obstacle for the counterbody material. After wear-in stage, the contact surface area between the mating surfaces is increased and and, in turn, the COF fluctuations are reduced. As for the hot-work steels tested under dry friction conditions, both grades end up with the sliding distance with the relatively high CoF, at a level of 0.9, exceeding those reported for cold work steels.

Figure 5 illustrates the wear factor K of the tested materials. It can be observed that the wear resistance of steel K340 is over twofold higher than that of the all reference materials. The results in this figure also reveal that steel K340 has abrasive wear resistance comparable as for the hot-work steel grade X40CrMoV5-1. The CrAlSiN thin film depostion on the K340 steel (sample denoted as

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K340/CrAlSiN) leads to a further significant increase in the abrasive wear resistance of this material compared to the other tested hot- and cold-work steels alike.

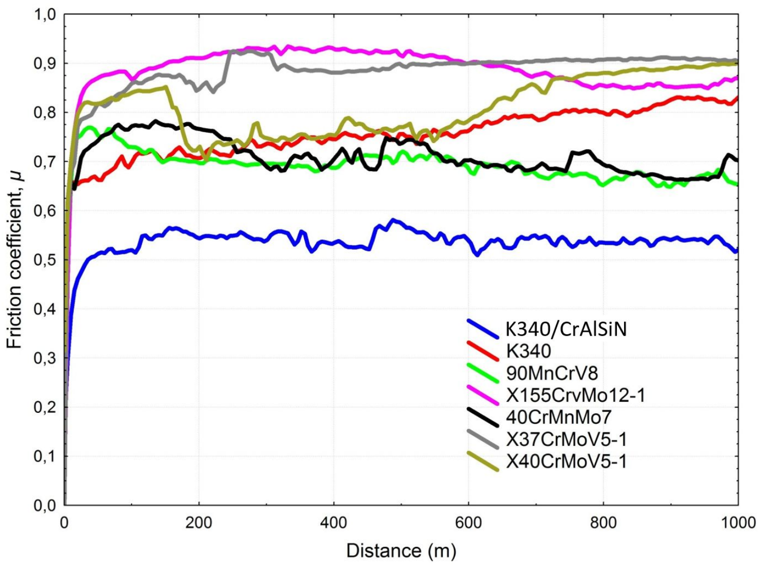

Figure 4. Curves illustrating variations in friction coefficient vs. distance for the tested materials

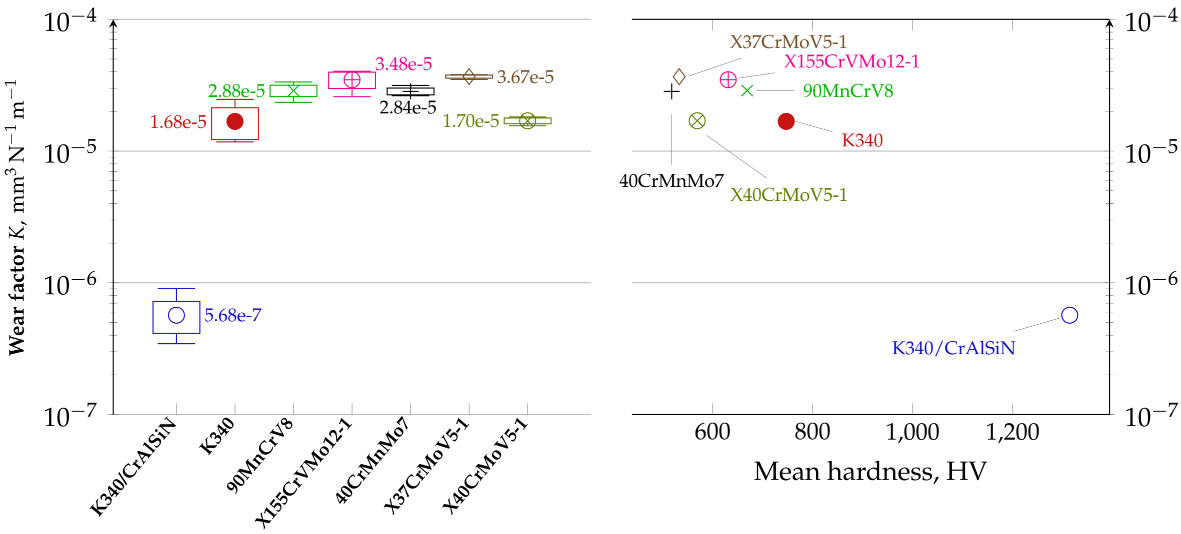

Figure 5. Diagram illustrating the wear factor *K* of the tested materials (left) and as a function of surface hardness (right)

Figure 6 shows the macro-photographs of worn surfaces. It can be observed that apart from the K340/CrAlSiN sample, for all tool steels the adhesive-smearing dominates in the wear tack. In the case of 4 steel grades with high values of the wear factor *K*, i.e., 90MnCrV8, X155CrVMo12-1, 40CrMnMo7, X37CrMoV5-1, the outside edges of the tracks additionally exhibit ploughing of the wear-products. This points to galling and cyclic upsetting of the high portion of the deformed tribofilm. This effect is the most noticeable in the wear track obtained for the X155CrVMo12-1 steel with the lowest wear resistance. Comparable material-deterioration morphology in the wear track, characterised by severe adhesive wear mode, was also observed for untreated Al-, and Cu-based metal alloys tested at ambient temperature under dry sliding [46].

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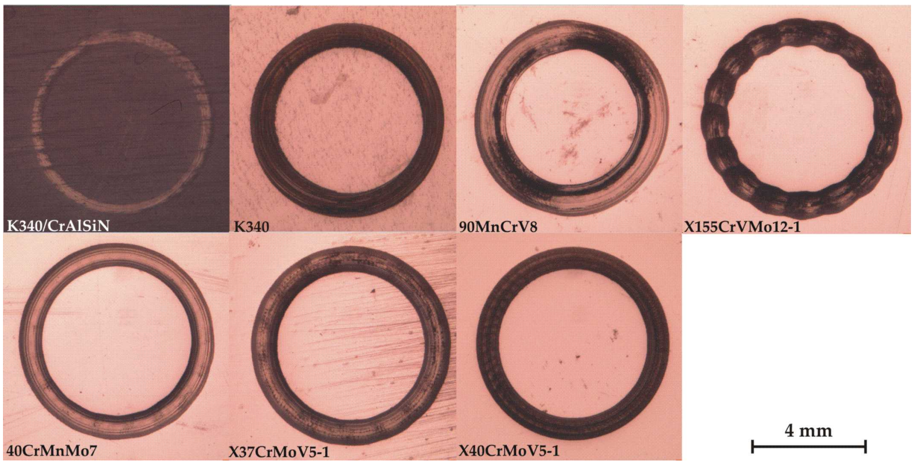

Figure 6. Worn surface of the samples tested under dry friction conditions

SEM examination of the obtained wear tracks made it possible to identify dominant wear mechanisms (Figure 7). The K340/CrAlSiN sample (Figure 7a) exhibited the abrasive nature of wear. The cyclic sliding process causes the the film cracking and fatigue-inducted delamination fallowed by the transfer of the spalling debris material through the wear track. Additionally, the nitride coating had lateral micro-cracks being the symptom that confirms the presence of fatigue. The wear mechanism for tool steels was affected by the adhesive wear. In the case of K340 sample (Figure 7b), the process of wear is primarily set up by abrasion and proceeded in abrasive-adhesive mode. The worn surface of the K340 sample shows the presence of characteristic parallel abrasive grooves and scratches caused by micro-cutting. In addition, the grooves have microcracks propagating perpendicularly to the sample movement direction. These microcracks result from low-cycle fatigue of the surface layer due to the cyclic upsetting of the material. At the same time there occurs adhesive wear, as demonstrated by the presence of the smeared tribofilm resulting from the transfer of secondary wear products.

The wear track surface of the cold-work steels (Figure 7c and 7d) reveals the presence of continuous scratches, which is typical of steel and is caused by the free displacement of wear products along the sample/counterbody contact trace. What is more, like in the case of steel K340, these steels also, simultaneously, undergo adhesive wear, which is particularly visible for 90MnCrV8 (Figure 7c). Krbata et al. [47] have demonstrated that the adhesive wear mechanism of this steel grade is more intensive at higher velocities during tribotesting. In turn, steel X155CrVMo12-1 exhibits the microcracking of carbides, which was probably caused by surface deformation of the material (Figure 7d). The carbide microcracks are the centre of fracture nucleation as well as fatigue spalling and may lead to tool damage, as demonstrated in [48]. An analysis of the wear surface of the 40CrMnMo7 sample (Figure 7e) shows the presence of abrasive wear (bright areas) and delamination together with the adhesive transfer of wear products along the wear path (dark areas).

The wear surface of the tested hot-work steel samples is similar (Figure 7f and 7g)with the exception of X37CrMoV5-1 where delaminations can additionally be observed on the wear track surface. The susceptibility to delamination of this steel grade can be explained by a relatively low hardness of this hot-work steel. As a result, this material is susceptible to this kind of plastic deformation. In addition, the microstructure of X40CrMoV5-1 due to high content of chromium and carbon, contains higher amount of hard phase [49], which could lead to its higher wear resistance than that of the X37CrMoV5-1 sample in the ball-on-disc test.

In the case of X40CrMoV5-1 steel (Figure 7g and 7h), the wear process was intensified by the additional impact of solid particles that – moving freely between the sample and counterbody surfaces – were rammed into the wear track surface. This behaviour leads to a higher abrasive wear of the tested steels. What is more, the hard carbides form a natural obstacle for the counterbody material.

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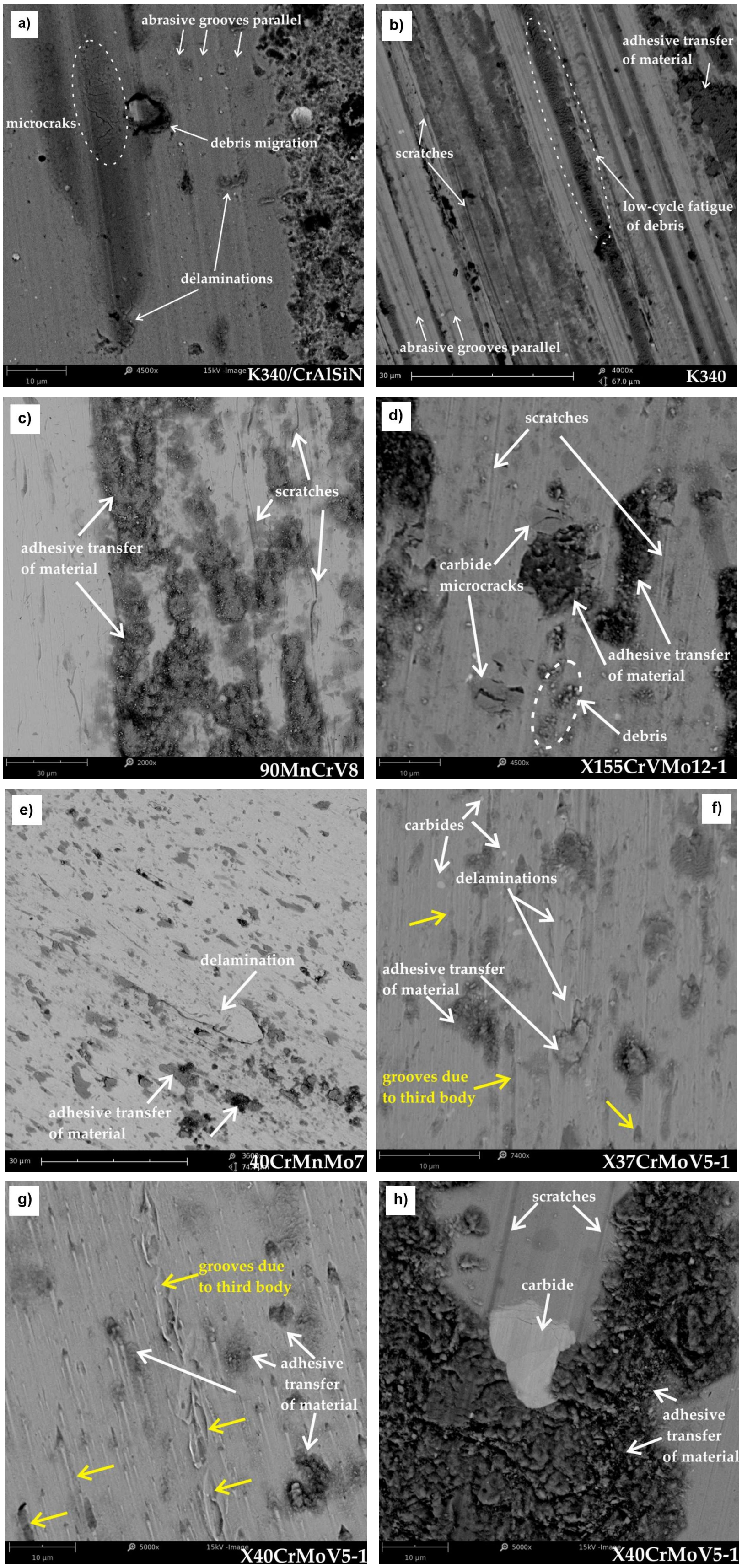

Figure 7. SEM microphotographs of the worn surfaces of: **a**) K340/CrAlSiN, **b**) K340, **c**) 90MnCrV8, **d**) X155CrVMo12-1, **e**) 40CrMnMo7, **f**) X37CrMoV55-1, **g**) and **h**) X40CrMoV5-1

4. Conclusions

The knowledge of tribological characteristics and wear mechanisms of materials make it possible to develop comprehensive criteria of their selection when designing products for tool steel in the manufacturing industry. This study aiming to comparatively investigate sliding wear behaviour and damage mechanisms of the K340 steel PVD-coated by CrAlSiN thin film and the reference set of cold- and hot-work tool steels.

According to the results of the ball-on-disc test conducted under dry sliding conditions, the highest wear resistance was observed for the tested materials in the following order: K340/CrAlSiN >K340> X40CrMoV5-1>40CrMnMo7>90MnCrV8> X155CrVMo12-1> X37CrMoV5-1.

The K304/CrAlSiN sample has a COF of 0.529 and a wear factor of $K = 5.68 \times 10^{-7}\,\mathrm{m}^3\,\mathrm{N}^{-1}\,\mathrm{m}^{-1}$. The sliding wear behaviour analysis demonstrated that the dominant wear mechanism for the tested tool steels was abrasive wear micro-cutting intensified by adhesive transfer of tribofilm material. Regarding the hot-work steels, deep grooves were visible on the wear track surface. In turn, the wear tracks of steel K340 showed the presence of parallel abrasive grooves. Generally, the PVD coated K340/CrAlSiN sample exhibited the abrasive nature of wear. Additionally, the nitride coating had lateral micro-cracks being the symptom of the simultaneously occurring fatigue inducted thin film spallation and material transfer.

Summing up, the CrAlSiN deposition onto nitirded surface of K340 steel reduces the wear and improves its sliding properties, which makes it a promising method for prolonging the service life of metalwork tools. Results presented in this study may prove useful for fabrication and prolonging the service life of cold-working tools.

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