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Original scientific paper

Analysis of Possibilities to Increase Products Durability

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Abstract: Increasing the service life of cutting tools in an adequate way remains a challenge. PVD coatings are often used for that. Therefore, the aim was to analyze the increase in the useful life of the trimming matrices by using TiAlN coating. The material that was analyzed is the high-speed steel HSS, from which the matrix subjected to analysis was made. The process of covering the matrix with TiAlN coating was analyzed and the average thickness of the obtained coating was specified. The chemical composition, structure, and adhesion for TiAlN coating on the matrixes were analyzed. The results of the extraction of the four matrixes were compared, where the number of work cycles for the matrixes without TiAlN cover was compared with the number of work cycles for the matrixes with TiAlN cover. In addition, factors that can affect efficient research with the Ishikawa diagram were analyzed. It was concluded that it is possible to get better durability of products by using TiAlN coating. The analysis and results can be useful to the coating on the tools used in industry with the aim to increase their life and to be useful in finding the factors which allow efficient research.

Keywords: coating of titanium and aluminum nitride; decision making; high speed steels; mechanical engineering; production engineering; single layer coatings; TiAlN

1 INTRODUCTION

The lifespan research of a product is particularly important for industrial applications [1, 17, 20, 23]. Currently, it is concentrated on machining, which is a basic production process [13]. Coatings are preferred to increase the service life of these tools [10]. Hard nitrides are commonly used as coating materials and are deposited using physical vapor deposition (PVD). Examples are, e.g.: TiAlN, TiN, or CaN, which are highly hard and resistant to wear. Therefore, these types of coatings are applicable in high-speed cutting tools that require increased mechanical properties and a longer service life [26]. Layers of titanium and aluminum nitrides (TiAlN) have become popular. It results from their outstanding mechanical properties, e.g.: hardness, resistance to corrosion, and wear. Additionally, TiAlN is characterized by low thermal expansion and conduction [10, 15]. TiAlN coating type has been used to increase the durability of different types of tools and machine parts. The increased life of the tools with TiAlN coating is achieved because of their structure or oxidation processes at elevated temperature.

For example, previous researches on TiAlN coating and the PVD methods for high-speed steel concerned among others: to obtain the optimal state of TiAlN coating on a high-speed steel fabric, with high microhardness and optimal coating thickness [12], the non-destructive and noncontact TWIN measurement for coated high-speed steels and oxidation steels including TiAlN applied to determine the thermophysical properties of PVD coatings [6]. Dry drilling analyses were carried out, showing that nanometric-scale TiAlN/TiAlZrN multilayer coatings exhibited better drilling performance compared to single-layer coatings such as TiN and TiAlN [7]. After testing two gears made of high-speed powder-hardened PVD steel (PV-HSS), coated with TiAlN (nano layer) and TiN (mono layer), it was concluded that TiAlN coated cutter worked better than the TiN-coated cutter [14]. The use of coated tools for machining is common because many coated tools show better performance compared to uncoated tools [25]. However, in the study [13], the properties of TiAlN were verified by measurement of electrochemical impedance spectroscopy (EIS). The next example is a study [10], in which the properties of the Al2O3-TiCN hard rolling properties of cutting tools for mentioned TiAlN coating were analyzed. In turn, the authors of the article [25] analyzed the anticorrosion properties by applying the method of cathodic arc deposition. Braic et al. [5] deposited TiAlN on carbon steel and high-speed steel (HSS), after which they verified, for example, chemical composition, texture, microhardness Vickers, and others. In turn, Shuai et al. [22] compared TiAlN (monolithic) with Ti/TiAlN (multilayered). This comparison included the mechanical properties and possibilities of cracking of the coatings.

After analyzing the literature review, it was concluded that achieving high efficiency of the tools remains a challenge [7, 13, 22]. Therefore, the aim was to analyze the increase in the service life of trimming matrices using a TiAlN coating and to demonstrate the improvements in performance during tool operation with this coating. The results of the study could be useful to improve tool life for different applications, mainly cutting tools that require high strength.

2 MATERIAL

The material used was high-speed steel (HSS), from which the analyzed trimming matrices were made. High-speed steel is a type of tool steel known for its good durability and cutting properties, as well as high ductility, impact resistance, and abrasion resistance [15]. It is commonly used in the production of metalworking tools such as trimming matrices, drills, cutters, and plastics molds [4, 15, 21]. The chemical composition of HSS is shown in Tab. 1.

Table 1 Chemical composition [%] of HSS [8]

C	Mn	Si	P	S	Cr
0,82 - 0,92	max. 0,4	max. 0,5	max. 0,3	max. 0,3	3,5 - 4,5
Ni	Mo	W	V	Co	Cu
max. 0,4	4,5 - 5,5	6 - 7	1,7 - 2,1	max. 0,5	max. 0,3

The subject of the research was the trimming matrix coated with TiAlN coating. The trimming matrix had been used in production (screw manufacturing), during which approximately 150000 cycles were completed (Fig. 1).

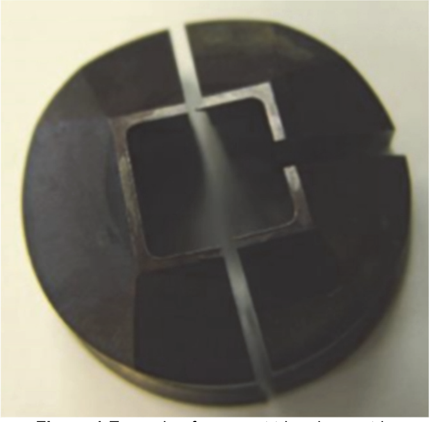

Figure 1 Example of worn-out trimming matrix

The basic properties of TiAlN coating are shown in Tab. 2.

Table 2 Properties TiAlN coating [10]

Microhardness HV 0,025	3000 - 3500
Thickness μm	1 - 7
Coefficient of friction μ	0,35
Temperature of the coating process °C	to 600
The working temperature of the coating max °C	900
Color	purple

The previously conducted research of trimming matrixes made it possible to choose the right type of PVD coating. For the research, a TiAlN coating was selected to extend the service life of the matrix operating under heavy loads. TiAlN is characterized by high durability and provides protection against erosion and abrasive wear [3, 9, 10]. Choosing the right relationship between the hardness and the residual compressive stress of TiAlN coating allows for increasing the stability of the cutting tool's edge.

3 METHOD

The process of preparing the trimming matrixes for coating with TiAlN coating was started with machining, and then the matrixes were subjected to thermochemical treatment. The process in which the matrixes were coated with TiAlN was started by washing the matrixes on the Vetter cleaning line. The washing process was supported by ultrasound and pendular motion; samples were washed for about 180 seconds at a temperature of about 53 °C in a chemical substance Galvex 17,30; intended for cleaning in the ultrasonic process. The samples were rinsed for approximately 18 seconds with deionized water in a reciprocating process and then dried with compressed air. The samples were washed for about 180 seconds at about 43 °C with slightly basic GP 17,40 powder for surface disinfection in ultrasonic processes. It was again rinsed for approximately 18 seconds with deionized water in the reciprocating process and dried with compressed air. At approximately 110 °C, the samples were dried with a stream of heated air. The samples prepared in this way were mounted on a planetary gear and placed in the chamber of the "DOMINO L" device with Oerlikon Balzers intended for applying the coatings. The coatings were prepared from sources of metal ions TiAl (50/50%) as well as nitrogen with a purity of 99,999%. The steps of applying TiAlN coating to the material began by creating a high vacuum that lasted about 1 hour, and the chamber of the device to about 450 °C. The surface was cleaned by argon ion digestion, where the argon treatment time was about 67 minutes, and the 300 V voltage was applied at about 500 °C and about 100 minutes to TiAlN coating of the HSS steel material according to the planned program. They were cooled in the chamber for about 180 minutes.

The research of the thickness of TiAlN coating on the trimming matrixes was made using the Kulzer tester by Sulzer Metaplast. The thickness of TiAlN coating of the two areas of the sample was measured five times. The average thickness in the two areas was calculated by adding five measurements for each area and dividing by the number of measurements. The chemical analysis of TiAlN coating for three areas of the sample was analyzed by emission spectrometry. Shell structure analyses were performed using the Hitachi S-3400N scanning electron microscope. Subsequently, the adhesion of the sample attached to the batch was measured by measuring the hardness with a stationary Rockwell 600A hardness tester manufactured by INNOVATEST. In the last stage of the analysis, the results from the exploitation of four trimming matrices were compared, where the number of work cycles was examined for matrixes coated with TiAlN coating and for matrixes not covered with TiAlN coating. The Ishikawa diagram, called the fish bone diagram, was used to analyze factors that could affect the accuracy of the analyses. Among the basic factors (i.e., 5M + E) [19, 23], factors such as man, machine, method, measurement, and environment were analyzed, because these factors were considered to have a significant impact on the effectiveness of the tests and correctness of the results [18].

4 RESULTS

The number of coating thickness measurements was five. The measurement included thickness from two areas. The results of the measurement of the thickness of TiAlN coating for two sample areas made of the cut matrix are shown in Tab. 3 and Fig. 2.

Table 3 Results of TiAlN coating thickness measurement

The number of coating thickness measurement / μm					Average thickness from areas / μm
1	2	3	4	5	
2,28	3,51	3,07	3,16	3,16	3,04
3,16	3,16	2,90	2,02	2,81	2,81
Average thickness from all areas / μm					2,93

The average thickness of the coating resulting from the thickness measurements of TiAlN coating of the trimming matrix was 2,93 μm. The results of the analysis of the chemical composition of TiAlN coating for the tree areas of the trimming matrix are presented in Tab. 4, and the results of the analysis performed on an SEM scanning electron microscope for the presence of given elements in TiAlN coating are shown in Fig. 3.

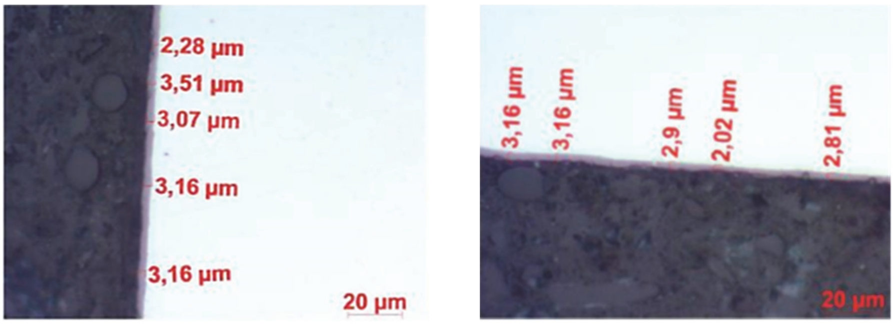

Figure 2 Results from TiAlN coating thickness measurement. Observation under the light microscope at 20 µm magnification

Table 4 Results from the analysis of the chemical composition of TiAlN coating (%)

Area	C	N	Al	Ti	Cr	Fe	Mo	W
1	3,93	24,48	19,38	31,55	1,01	17,60	0,92	1,11
2	4,60	23,22	19,64	30,64	1,08	20,16	-	0,65
3	2,97	24,21	20,28	31,92	1,06	17,64	-	1,42

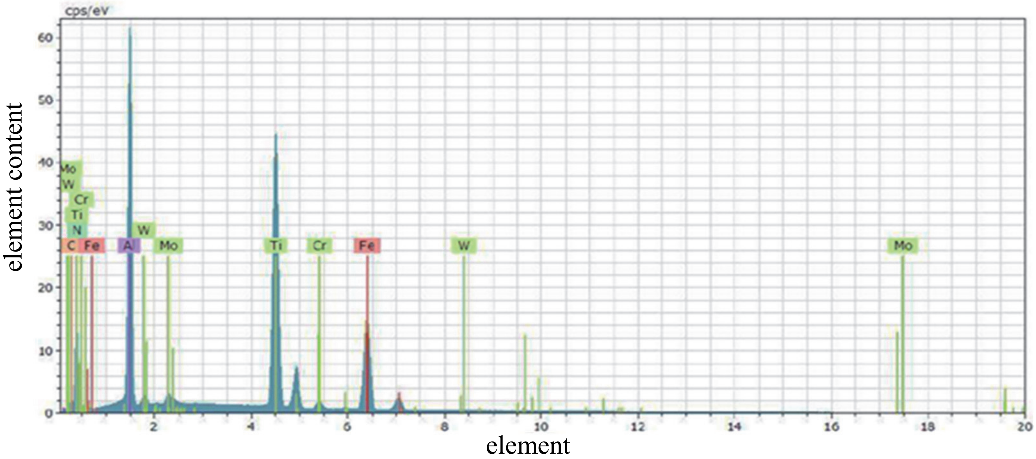

Figure 3 Results from the analysis performed on a SEM scanning electron microscope for the presence of given elements in TiAlN coating

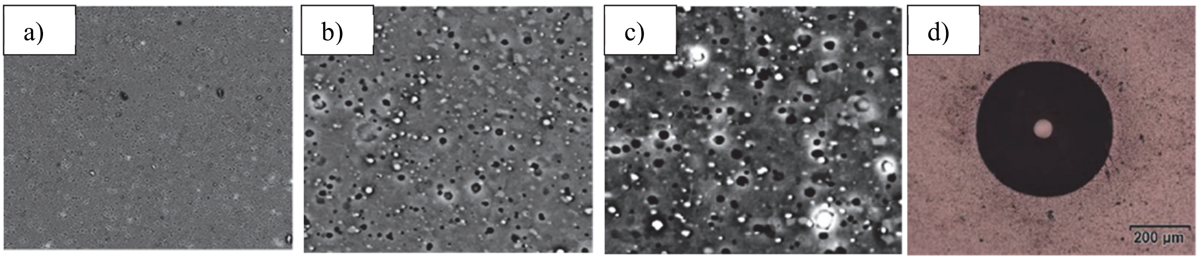

Figure 4 Structure of TiAlN coating: (a) 1000x; (b) 5000x; (c) 7000x; (d) deformation of the adhesion measurement specimen

The average content of given elements in the surface layer of TiAlN coating: C - 3,83%, N - 24,14%, Al - 19,77%, Ti - 31, 37 %, Cr - 1,05%, Fe - 18, 47 %, Mo - 0,92 %, W - 1,06%. In the case of elements' content, i.e.: Fe, Mo, W, Cr, and C in the surface layer; their content may result from the measurement method, because these elements from the native material do not occur in TiAlN layer.

Examples of the analysis of TiAlN coating structure and the deformation of the adhesion measurement sample are shown in Fig. 4.

The nonconformities were not identified after analyzing the structure of TiAlN coating at a magnification of 1000x, 5000x, and 7000x, respectively. There were no cracks or delaminations on the surface of the sample, which showed good adhesion of the coating to the substrate.

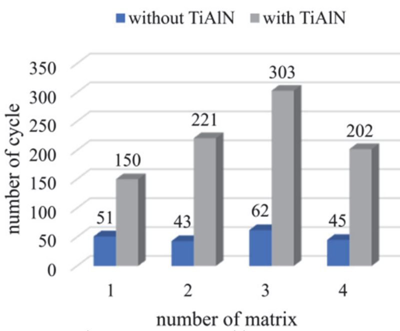

Figure 5 Results from the analysis of four trimming matrixes coated with TiAlN coating and without TiAlN coating in terms of the number of cycles in the operation process

An analysis was carried out comparing the results from the exploitation of four trimming matrixes, where the number of work cycles for coated TiAlN coatings and for non-TiAlN coated matrixes were examined. The results of the analysis are shown in Fig. 5.

The results of the analysis showed that the matrixes with TiAlN coatings have a longer life than the matrixes without TiAlN coating.

5 DISCUSSION

Improving the quality of cutting tools remains an open problem [7, 12, 26]. Also, by comparing the performance results of TiAlN-coated tools with other types of coatings, it was shown that the surface morphology of TiAlN housing was smoother than CrAlN. Also the thickness of TiAlN was larger. However, lower parameter values were obtained for hardness and modulus of elasticity, where the CrAlN coating was more advantageous, as shown in [11]. In addition, as confirmed by the authors of the study [24], TiAlN coatings are more resistant to wear than other coatings, e.g. CrN, especially in the case of corrosion, oxidation or abrasion. Similar conclusions were observed in the case of analyses carried out by [28], where it was shown that in the case of thin, single-layer TiAlN coatings, a faster corrosion process occurs. Another example is the article [2], in which, by measuring the mechanical properties and scratch resistance of coatings (e.g. TiN/TiAlN, CrN/TiAlN, and CrAlN/TiAlN), it was shown that their durability and modulus of elasticity profile are higher in the case of two-layer coatings. At the same time, they show a limited effect on the friction coefficient (or its absence) in the case of interlayer coatings. Subsequently, as in the study [27], TiAlN, AlCrBN and TiAlN/AlCrBN coatings were deposited on cemented carbide by cathodic arc evaporation method. Among others, TiAlN/AlCrBN coating achieved excellent high temperature oxidation resistance and stability.

In this case, after the analysis of TiAlN coating, it was shown that it provides an increase in tool life. After the research, it was concluded that at temperature 500 °C and time about 100 minutes it is possible to achieve the average thickness of TiAlN coating equal to 2,93 μm. The result of the analysis may influence other factors which should be considered during further research of the service life of TiAlN coatings. These factors are presented in the Ishikawa diagram (Fig. 6).

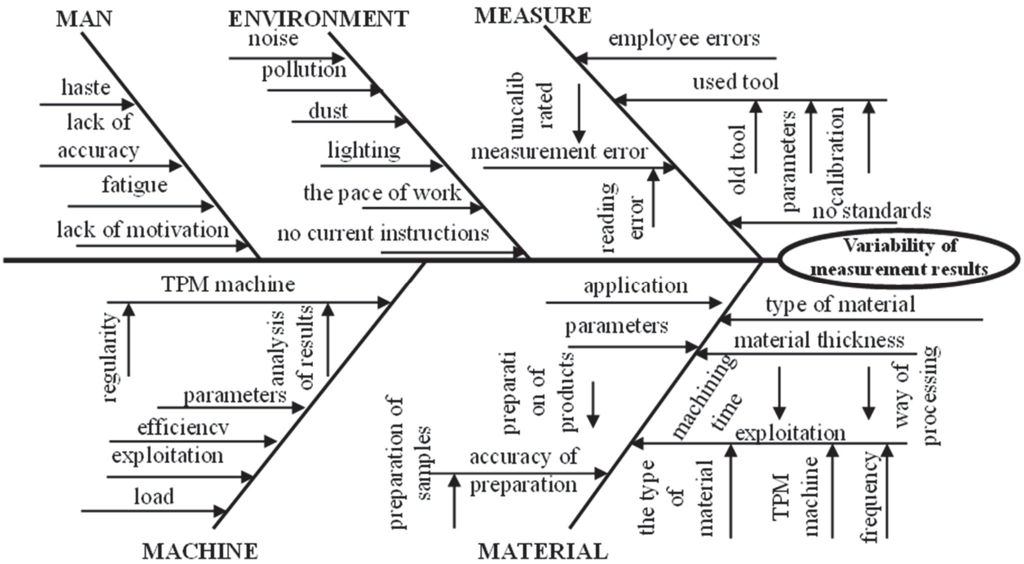

Figure 6 Ishikawa diagram with the factors influence on measurement results

During the next research of the measurement of the life it may be useful to consider the factors which could cause the variability of results. It should be noted that workers work both during preparing the samples for research and during the use of samples on the machine. The method and the systematic measurements are important, as well as the work according to the standards. The important factors are the machine used, tools and material, influenced by indirect factors, i.e.: type of material, parameters, efficiency, TPM, load, the way of processing and time of exploitation. It would be necessary to observe the environment of work, for example, lighting and order in work positions, which are sometimes neglected but can influence the results of measurement.

6 CONCLUSION

After the research, it was concluded that at temperature 500 °C and time of about 100 minutes it is possible to achieve the average thickness of TiAlN coating equal to 2,93 μm. The analysis did not mention any incompatibility with TiAlN coating on the trimming matrix and the absence of cracks and delamination on the surface of the sample, which proved the good adhesion of the coating to the substrate.

The analysis of the possibility of increasing the life of the trim matrices with TiAlN coating showed that the trim matrices with TiAlN coating (thickness 2,93 μm) were characterized by about four times longer life, indicating their better performance.

It was concluded that the trimming matrixes with TiAlN coating performed several times more cycles than the matrixes without TiAlN coating, that they were of good quality and did not require additional regeneration during operation, significantly acting on the economic effects associated with production.

It was shown that the TiAlN coating is useful for increasing the life of tools used in industry (for example - production of screws). It seems appropriate to make the next research in which the influence of the coating thickness on the increasing life of the matrixes will be analyzed. The analysis and results can be based on applying TiAlN coating on the tools used in industry with the aim to increase their life, and the proposed Ishikawa diagram can be useful in finding the factors which allow efficient researches.

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