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ON THE EFFECT OF ADVANCED PVD COATING ON PERFORMANCE OF CUTTING DIES IN AUSTENITIC STEEL

Miroslav Piska & Kristyna Holkova

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Abstract

Effective machining of austenitic steels has been a long-term challenge due to the unique combination of mechanical properties, strain hardening, poor heat conductivity, and tendency to build up-edge formation of the steel when cutting. The round HSS cutting dies M10x1,5-6g, uncoated and PVD-coated with sputtering technology - TINALOX® GOLD, ALOX SN^2, and HIPIMs technology - FerroCon®, FerroCon ®+Ti,Al(C,N), three samples per each variant, produced in the company CemeCon Ivancice, Czech Republic. All PVD-coated cutting dies showed ~~a~~ very good cutting performance compared to the uncoated HSS dies, prolonging the tool lives 4-9 times overall. The longest effective time of chip formation for TINALOX® GOLD was 43-45 minutes. The higher recorded temperatures of chips (107-111°C) resulted in better formability of the material, compared to 104-105°C for uncoated HSS tools. The PVD coatings worked like ceramic insulators, preventing intensive heat flux into the tool, and enhancing ~~so~~ the plastic deformation of the austenitic steel. The best results for the round HSS cutting die were achieved repeatedly with the sputtering technology - TINALOX® GOLD, which provided excellent tribology between the tool, chip, and workpiece and high-quality threads.

Keywords: austenite; threads; PVD; wear; quality;

1. Introduction

Thread production is a widely used industrial operation that can be utilized in many ways for producing internal or external threads [1],[2],[3],[4]. Internal threads made by tapping are easier to test due to better access to the workpiece and dense hole arrangement. However, there is worse access for direct measurement of surface quality inside, so a precise splitting of samples is needed. There are many trends in the optimization of the technology [5],[6], nevertheless, the prevailing cutting materials in practice are HSS, protected with TiN, Ti(C,N) or Ti(Al,N) coatings made by physical vapor technologies (PVD) [7],[8]. The reason for HSS stems also in higher cutting speeds needed for cemented carbides that generate also high feed speeds, which can be a hazardous operation. The success in the coating of cutting flutes with hard and resistant layers depends not only on many physical and technological parameters of the deposition itself but also on the pre-processing of the functional tool surfaces [9],[10],[11],[12],[13]. The physical vapor deposition techniques, such as arc evaporation or magnetron sputtering, transport the atomic material according to the bias voltage and electromagnetic field in curved paths from the source to the substrate. It results in irregular crystallization of the coating layer on the substrate, especially at the tooltip, and a breakage of the tip can occur easily. On the other hand, a shadowing effect results in the growth of an inhomogeneous film, so apart from thinner layers, poor adhesion can be found. This effect can be suppressed effectively by high-power impulse magnetron sputtering and a higher ionization rate of deposition material [14],[15]. The incoming particles have higher arrival energy and can align themselves in the shape of the substrate. By the HiPIMS discharge, a plasma density of up to 10^{19} m^{-3} can be achieved, resulting in the ionization degree of the target material up to 90 % [16]. The presence of energetic particles in the flux of coating material not only enables the coating of substrates placed perpendicularly to the target [17] but also effectively changes the morphology and associated properties of the coating. The coatings deposited by HiPIMS were reported to have a smooth, droplet-free surface [18], increased hardness [19], density [20], and adhesion [21]. In addition to that, HiPIMS also allows better control of thin film growth by phase tailoring [17], selective substrate biasing [22], or guiding the deposition material to the desired area of the substrate [23].

Furthermore, the optimal radius of a cutting edge at the recommended mesometric scale (in the order of magnitude ranging from 1 to 100 μm) [9] and it is difficult to reach also. These technologies belong to the know-how of many companies dealing with coating because effective coating depends on the surface quality, exact radius of cutting edge, etc. The standard methods for measurement of coating thickness by the so-called *kalotest* are replaced by more sophisticated measurements using X-Ray spectrometric methods [24].

The wear and tool life of tools for the production of threads can be studied from several aspects directly [25] or indirectly via torque analyses [26]. The torque data is possibly the most relevant signal for tool wear of tap tools according to the concept of Industry 4.0.

Precise machining of austenitic steels [27],[28],[29] is associated with many problems and difficulties due to the mechanical properties of the material. High strain hardening and low thermal conductivity can be mentioned as ~~the~~ typical problems resulting in long chips, high cutting temperatures, and a tendency to produce built-up edges. Testing of external threads made by a cutting die seems to be problematic in general, because of the limited length of tested samples and costly experiments. PVD coating seems to be problematic regarding the accessibility in the cutting die hole and grooves, but the worst problem stems from the complicated deburring of cutting edges needed for coating. Our previous industrial research has shown that the important reasons causing premature edge breakages and the production of wrongdoings are as follows:

- wear of tools that cannot be easily quantified or predicted safely in workshop conditions,
- non-standard or inferior quality cutting dies,
- non-convenient cutting speed,
- a mismatch of machine feed can cause the tool to break in tension or compression,
- a misalignment of the cutting die and workpiece axes,
- ~~a~~ clogging with chips due to poor cutting performance and poor chip evacuation,
- ~~a~~ poor cooling or lubricating (~~a~~ use of improper cutting fluid or not powerful cooling flow).

Many of the problems can be detected with force sensors or energy consumption because they reflect the forces and cutting conditions [30], however, the number of applications ensuring the top quality of threads without any flaws is booming. The integrity imperfections can be harbors for infections, places for contaminations, or fatigue crack nucleation. The basic aim of this work is to find the best cutting material for excellent thread production made by round cutting dies.

2. Experimental Works

The material of the workpiece was austenitic stainless steel, CSN 10088-1 1.4301 (X5CrNi 18-10), with dimensional and shape deviation tolerances according to EN 9445– Table 1,2. The material is the most used stainless steel, referred to by the consumer names food-grade or 18-10. It is used in the food, pharmaceutical, and cosmetic industries, as well as in facade and residential architecture. The blank rods ϕ10h6/6000 mm were cut and machined to the dimensions according to Fig.1. The fastened workpieces were prevented from unwanted rotation with a hardened cross pin ϕ3 mm and mounted to a 3-jaw chuck in the machine spindle VR5A (Kovosvit, Sezimovo Usti) controlled with the Sinumerik 802D. The cutting dies were clamped to a standard holder, which was fastened to a 3-jaws chuck and fixed with screws on the top of the dynamometer KISTLER 9272. The radial alignment at the end was below 0.05 mm. The dynamometer set was placed into the CNC drill press– Fig. 2. Kistler dynamometer 9272, charge amplifiers 9011, and the Dynoware program for force and torque analyses of the sample loading were used. The sampling rate of 60kHz, the low-pass filter, and the long-time constant were set for all data acquisition. A special CNC program was written for the automatic control of the cutting operations.

Chemical composition (weight %)				
C	Si	Mn	P	Ni
≤0.08	≤0.10	≤2.0	≤0.045%	≤8.0-10.5
Cr	S	Fe		
18.00-20.00	≤0.030%	balance		

Table 1. Chemical composition of the tested material

Yield point R_e [MPa]	Tensile strength R_m [MPa]	Young modullus [GPa]
240 - 250	520 – 640	190

Table 2. Mechanical properties of the tested material

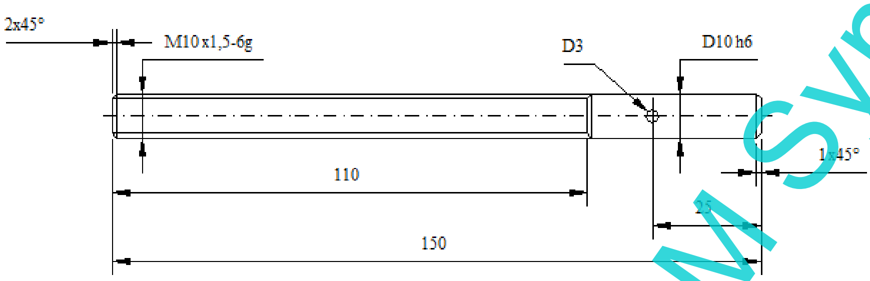


Fig. 1. Sketch of the specimen

a) b)

Fig. 2. Experimental set-up: (a) Kistler 9272 set-up and the machine (in the background); (b) a detail of the thread-cutting operation

The round cutting dies SE-B-gel-VA (Emuge Franken, Germany), article number D0103500.0100, constructional design DIN EN 22568, geometry VA, right-hand sense of rotation, lapped surface quality made from cutting material HSSE were used. Chamfer length was 2 threads, so 8 cutting edges effectively cut the specimen. Round HSSE die is recommended for universal application in stainless steel with excellent quality on the best CNC machines. Nevertheless, the cutting edges were not burr-free, so the ultrasonic polishing machine Piggy Sonic Mark 3 (NOVAPAX CZ s.r.o., Prague, Czech Republic) and diamond micro-grinding tools had to be used before the PVD coating - Fig. 3.

The cutting dies were tested as uncoated, but also PVD coated with unit CC800®/9ML Flex HiPIMS (CemeCon, Wurselen, Germany) working in the standard sputtering technology as CC800® (Tinalox Gold®, Alox SN^2) and FerroCon® and FerroCon® + TiAl(C,N)® working in the HiPIMS regime – Table 3. Each combination was tested three times. The PVD coating was made by the company CemeCon s.r.o., Ivančice, Czech Republic. The coating unit has six cathodes equipped with shutters. Two cathodes with pure Ti targets (99.999%) were used in DCMS mode for etching and four Ti targets with embedded Al slugs were powered by HiPIMS to provide the coating material.

a) b) c)

Fig. 3. Deburring of the cutting edges of the round dies: a) before polishing, b) after polishing, c) after polishing and coating

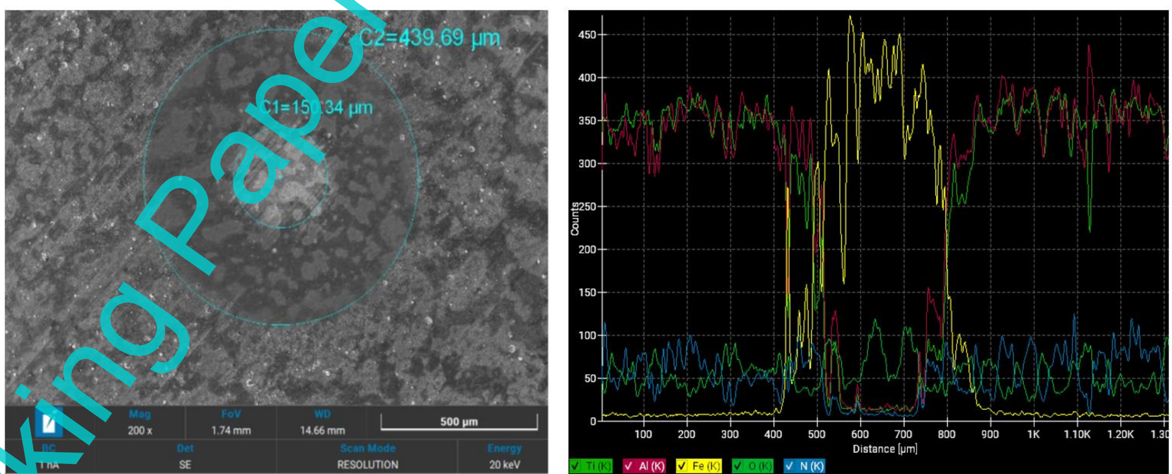
The die was placed at the central substrate table, and the axis of the die was oriented perpendicularly to the target surface. Prior to the coating, etching with Ti ions was performed. The average power on the cathodes was 11.95 kW. A bias voltage of –59 V was applied to the substrate table. A mixture of nitrogen, argon, and krypton gases was used, with flow rates of 240, 311 and 213 ml.min^{-1}, respectively. The deposition rate was 39 nm.min^{-1} approximately. The scanning electron microscope MIRA3 (TESCAN, Brno, Czech Republic) was used for analyses of the secondary and backscattered electrons (SE, BSE), energy-dispersive X-ray spectroscopy, and measurement of the real thickness of the coating t – see Fig. 4 - according to equation (1):

$$t = \sqrt{R^2 - (\frac{C1}{2})^2} - \sqrt{R^2 - (\frac{C2}{2})^2}, \qquad (1)$$

where R is the radius of the polishing ball, C1 represents the outer diameter, and C2 is the inner diameter of a dent in the surface.

Coatings	Structure	Microhardness HV 0.05	Maximal working temperature [°C]	Thickness [µm]
Tinalox Gold®	monolayer, $Ti(Al_xN_{1-x})$ supernitride	2300	600	2.8-3.0
Alox SN²	multilayer, nanocomposite	3500	1100	2.7-2.9
FerroCon®	nanocomposite	3800	1100	2.8-2.9
FerroCon® + Ti,Al(C,N)	multilayer, nanocomposite	3800	1100-1150	2.9-3.0

Table 3. An overview of the coatings and their specifications (some details presents a company know-how)



a) b)

Fig. 4. The principle of coating thickness measurements – the kalotest (a) and the linear EDS with the distribution of elements across the section, corresponding with the diameter of the ball and thickness of the layers

Cutting speeds 2.8-3.9-5.3-7.0-9.4 m/min were set in the tests, but the basic speed was 2.8 m/min. The cutting oil FUCHS ECOCUT 532 LE was used for the lubrication of machined surfaces. The ECOCUT 532 LE is a high-performance cutting oil that is chlorine-free, for machining difficult (stainless) materials and very difficult-to-machine materials (density at 15 °C - 0.94 g/ml, flashpoint 210 °C, kinetic viscosity at 40 °C 32 mm²/s). The oil was applied to the tool with a brush during all cutting and chip production. The temperature of the cutting was recorded by the thermo-camera FLIR EP XT. The instant inspection of the threads was conducted by the caliper M10x1,5-6g VÖLKEL (MT Nastroje, Moravska Trebova, Czech Republic) and by the micrometric caliper INSIZE Czech, Ivancice). The shape deviation and quality parameters were checked by the Bruker Alicona IF G5, Graz, Austria, and by the optical microscope 3D SMART (HotAir, Ostrava, Czech Republic).

3. Results

The selected time series of the torque moments for dies with different coatings can be seen in Fig. 5. All coatings performed very well, but they differed in the stability of the torque moments reflecting the chip production.

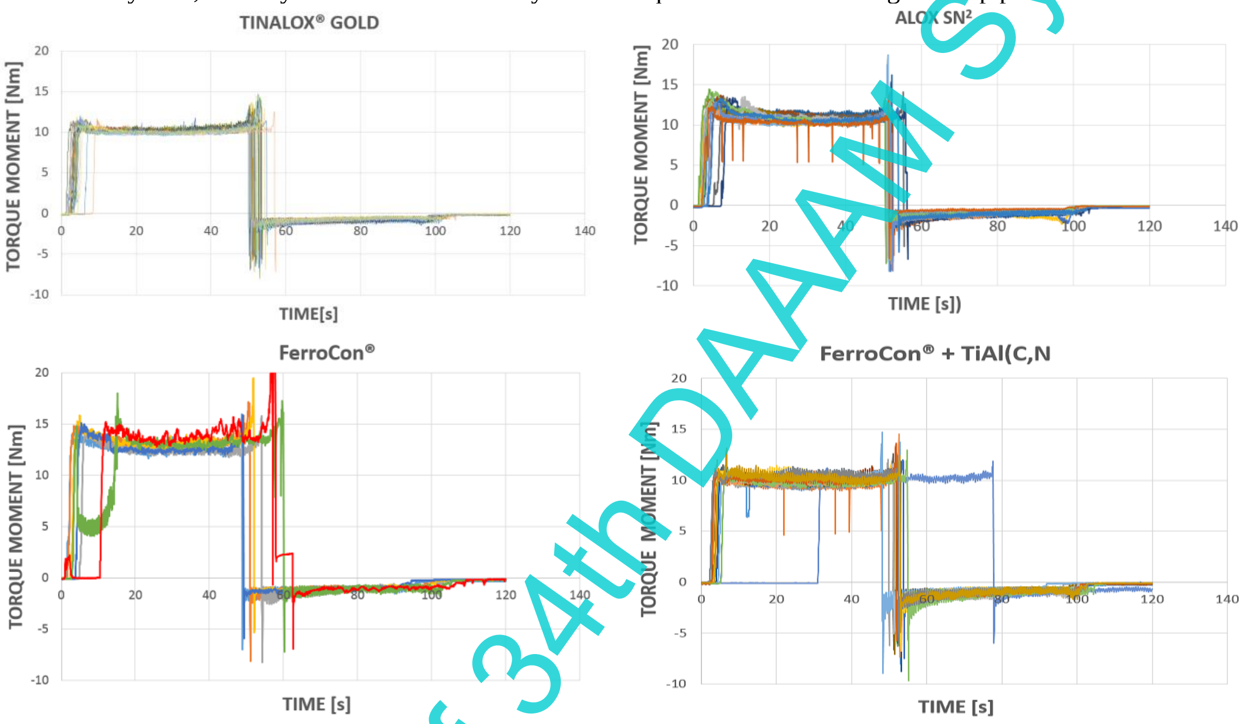


Fig. 5. The time series of torque moments for various PVD coatings

The TINALOX® GOLD and ALOX SN² exhibited excellent performance even at increased cutting speeds – Fig. 6, where no rise in torque moment was measured.

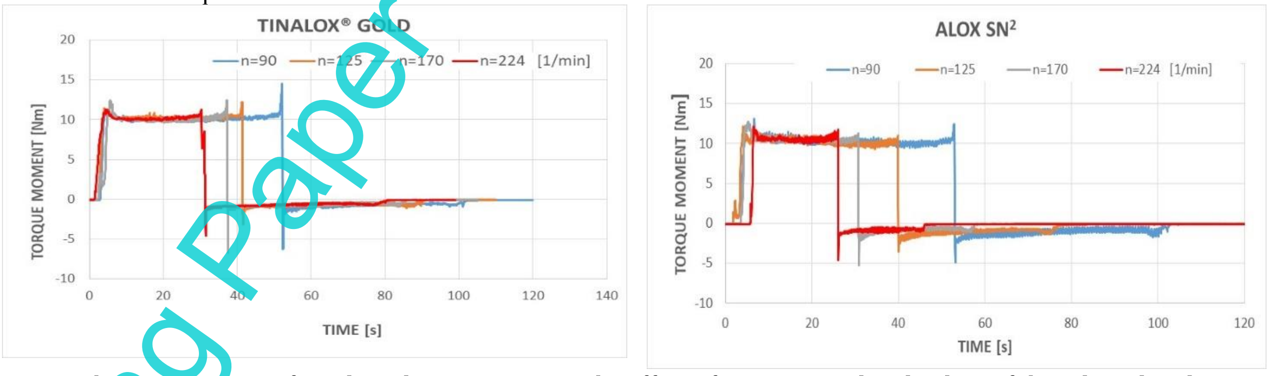


Fig. 6. The torque courses for selected PVD coatings - the effect of cutting speed on loading of the selected tools

The analysis of the cutting die design confirmed an irregular undeformed chip cross-section, but the specific cutting force acting on the cutting edges [30] was approximately stabilized – Fig. 7. It confirms a very good cutting geometry from the producer, because no cutting edge is too overloaded.

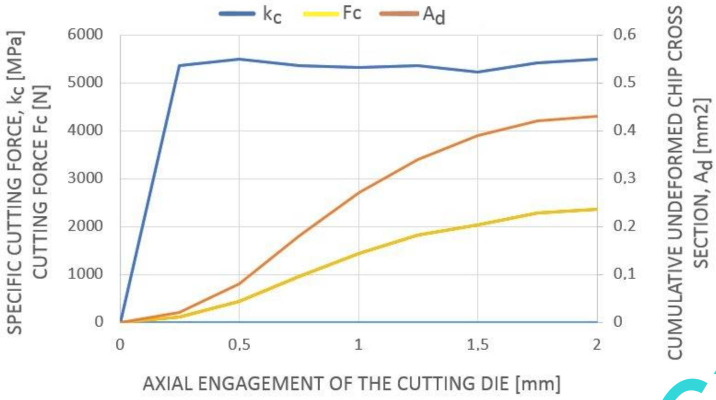


Fig. 7. A detailed analysis of the undeformed chip cross-section Ad, torque moment, cutting force Fc and specific cutting force kc acting on the cutting edges at the beginning of cutting (a selected pass of the TINALOX ® GOLD).

The thermal fields showed the following ranges of maximal temperatures for the cutting materials (Fig. 8):

- HSS: 104-105°C
- Tinalox Gold®: 107-111°C
- Alox SN^2 : 114-117°C
- FerroCon® + TiAl(C,N)® : 118-127°C
- FerroCon® : 128-130°C.

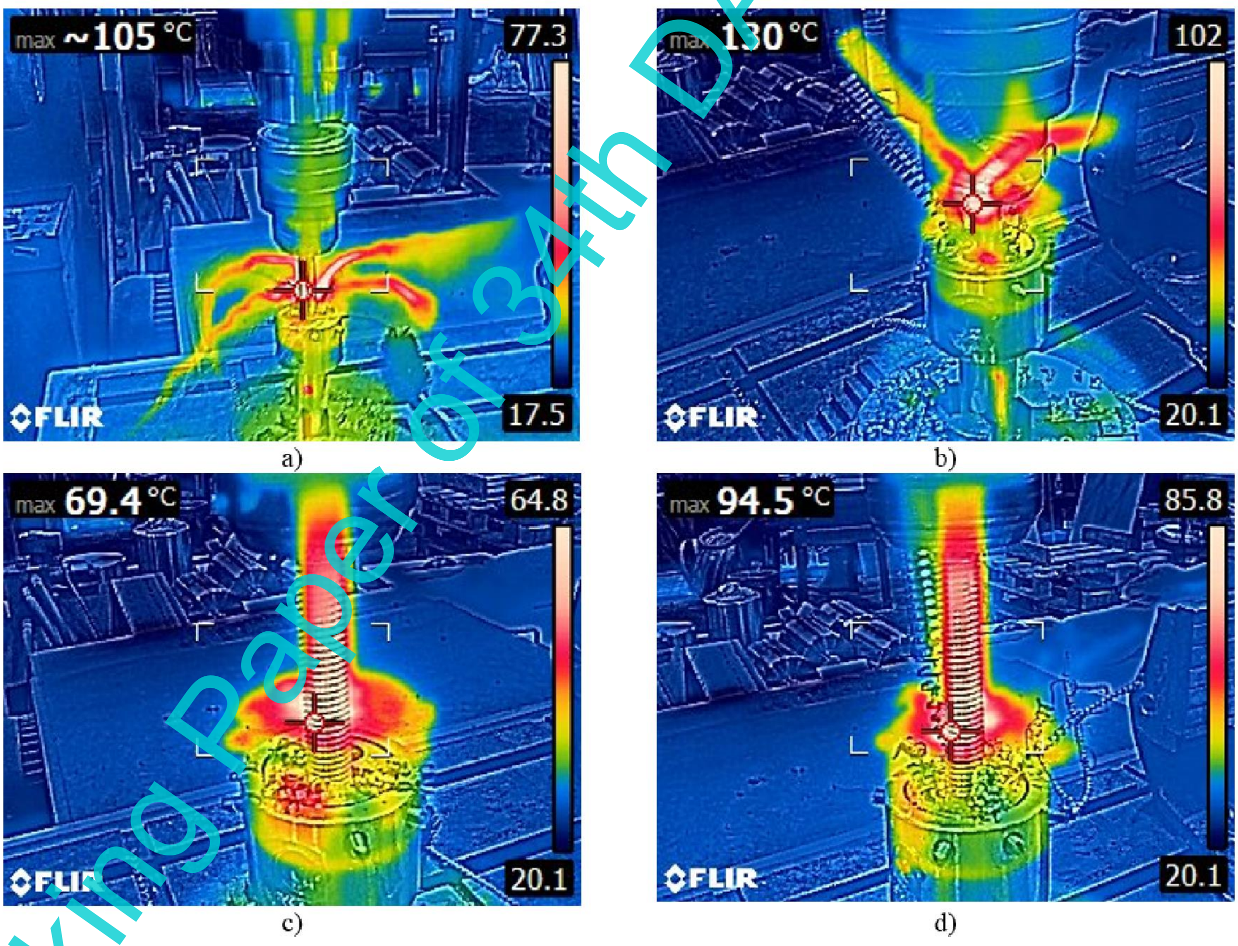
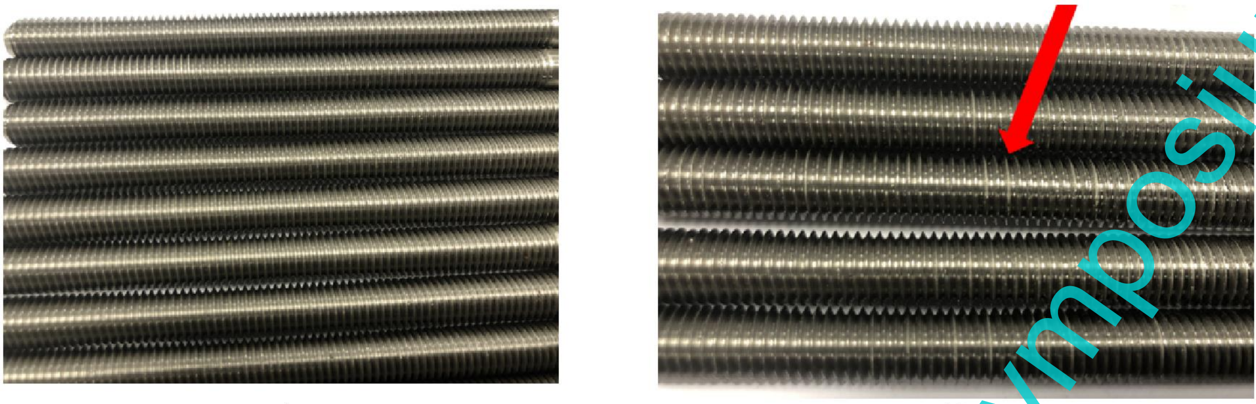


Fig. 8. Distribution of temperatures when cutting threads with a round die: a) uncoated HSS, b) HSS coated with FeroCon®, c) the workpiece after cutting by uncoated HSS, d) the workpiece after cutting by HSS coated with FeroCon®.

The change in surface quality could be seen visually first because of the change in the light contrast– Fig. 9.



a) b)

Fig. 9. Selected samples: a) excellent surface quality of the tested samples, b) first appearance of defects on the surface

Analysis of surface morphology by Alicona Infinity Focus G5 revealed many deviations from the right shape and dimensions of the threads – see Fig. 8,9. Most of them were initiated by the built-up edge, chipping of the edge, and a combination of the phenomena. However, excellent profiles have been found for the majority of the samples (except for uncoated HSS), and chip removal was running smoothly – Fig. 10.

According to the quality of the threads, stability of the torque moment, and some other wear effects, the total cutting performance can be seen in Fig. 11.

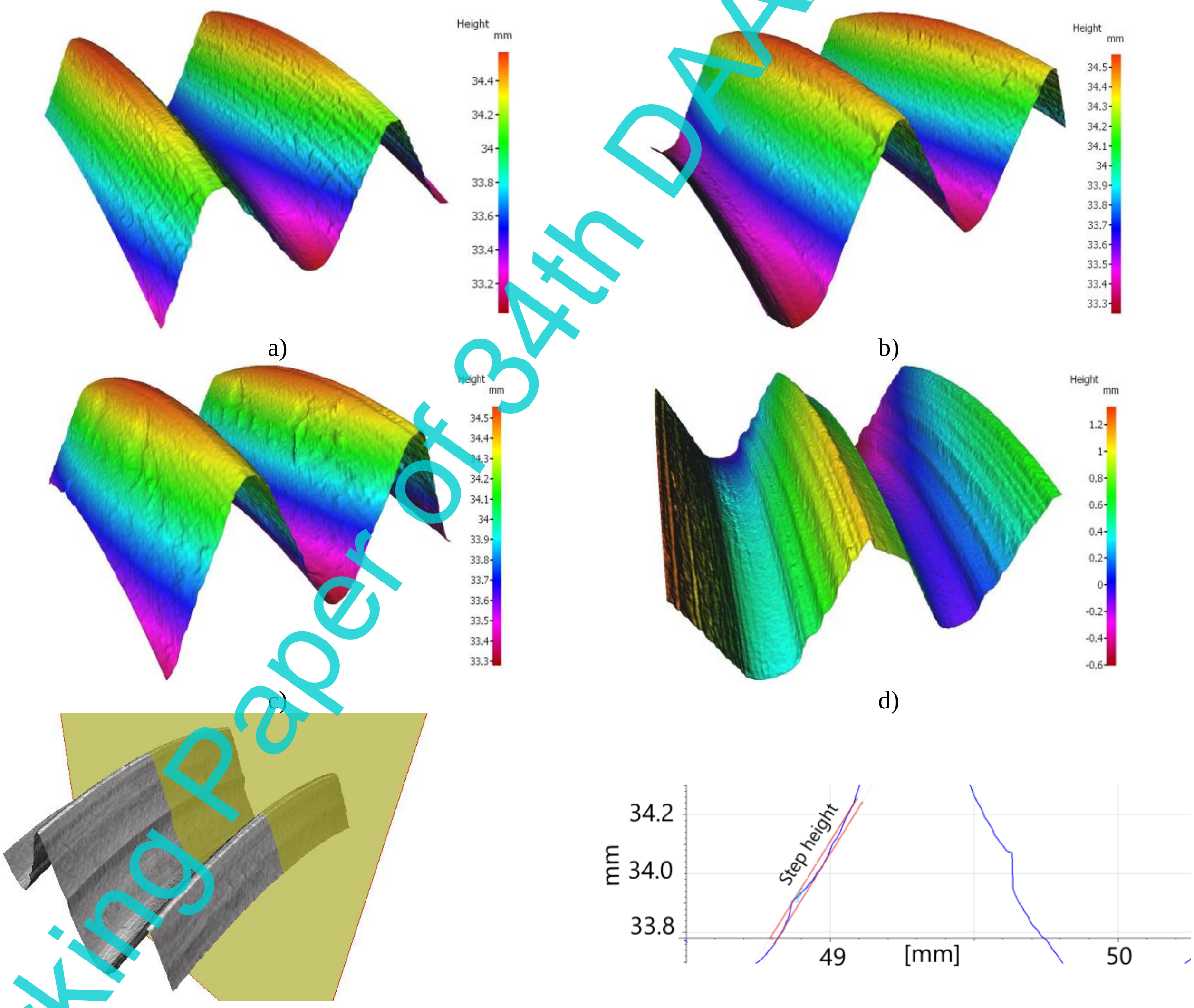
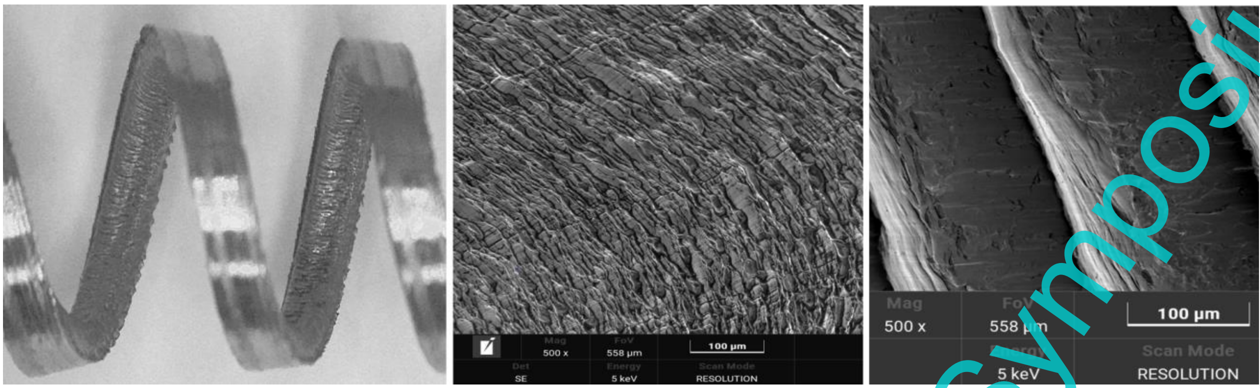


Fig. 10. An overview of typical results a) the correct design of the thread, b) incorrect crest, c) side defects, d) completely affected all produced surfaces, e) a cross-section of the threads, f) evaluation of the shape discrepancies in the thread design.



a) b) c)

Fig. 11. Chip produced by the TINALOX® GOLD coating: a) overview of the chip, b) detail from the chip, c) a magnified detail of the chip – a production of fine segments, with the convenient plastic flow of the austenite

Fig. 12. The average tool life of the tested cutting dies. The integrated criterion of the wear was applied – a deterioration of the surface quality, irregular torque moment when cutting, and edge chipping.

4. Discussion

The experimental results confirmed the previous results in phenomena that could be expected in the technology of thread production in austenitic steel [27-29]. However, the standard sputtering technology is exhibited to prevail due to better tribology of the tested coatings against steel in the test conditions where the hardest coating is more sensitive to edge chipping and production of built-up edges, affecting the design of tools and produced threads. The higher temperatures of chips and workpiece surface seduce to exclude the lubrications, however, such tests ended with catastrophic failure and fracture of tools.

5. Conclusions

The four hard coatings have been proven to be very effective in thread cutting in austenitic steel AISI 304, all of them much better compared to the uncoated HSS round dies. The coatings provided a high wear resistance and prevented the cutting edges from production of built-up edges, and cold welding of the chip to the cutting tool.

The longest effective time of chip formation for TINALOX® GOLD was 43-45 minutes. The higher recorded temperatures of chips (107-111°C) resulted in better formability of the material, compared to 104-105°C for uncoated HSS tools. The PVD coatings worked like ceramic insulators, preventing intensive heat flux into the tool, and enhancing ~~so~~ the plastic deformation of the austenitic steel. The higher working temperatures resulted in a more convenient plastic flow of workpiece material and higher quality of the cut surfaces. The production of built-up edges is the worst problem in austenitic steel because it affects the thread quality and integrity. The best results with TINALOX® GOLD and ALOX SN^2 reflect good tribological properties. The phenomenon of BUE can be detected by the torque measurements, where sudden drops or rises in the loading reflect the problem, and the production of defective threads follows. Anyway, to reach such good results with PVD coatings for threading in austenite steel means that the dies must be free of any burrs after grinding or polishing. These results are important for the next improvement of cutting die production – the PVD technology can significantly increase the cutting performance of the tool, but an effective deburring of the acting edges is needed. Ultrasonic polishing with diamond tools proved to be a very effective way for it, but it should be automatized or the CNC grinding machines should be able to do it. Perfect integrity of the tool surface and advanced PVD coating prevent built-up production and enhance the quality of threads, tool life, and economy of the production. The best results for TINALOX® GOLD will be tested also for tool-supportive guides (e.g. reaming heads) and work materials suitable for welding.

6. Acknowledgment

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7. References

[1] Tlusty, J. (1999) Manufacturing Process and Equipment. 1st edition. Prentice Hall, 928 pp. ISBN 10-0201498650.
[2] Shaw, M.C. (2005) Metal Cutting Principles. Oxford University Press, 2nd ed., pp. 651, ISBN 0-19-514206-3
[3] Black, B.J. (2010) Workshop Processes, Practices and Materials. 4th ed., Elsevier Ltd, Oxford, UK.
[4] Patel, H.J.; Patel, B.P.; Patel, S.M. (2012) A review on thread tapping operation and parametric study. International Journal of Engineering Research and Applications (IJERA), 2(3): 109–113
[5] Fromentin, G., Poulachon, G., Moisan, A. (2002). Thread forming tapping of alloyed steel, ICME Proceedings, Naples, Italy, 115-118.
[6] Píška, M.; Sliwkova, P. (2015) A study of cutting and forming threads with coated HSS taps. Journal of Machine Engineering, 15(3): 65–74
[7] Bouzakis, K.-D.; Michailidis N.; Skordaris, G.; Bouzakis, E., Biermann, D.; M'Saoubi, R. (2012) Cutting with coated tools: Coating technologies, characterization methods and performance optimization. CIRP Annals – Manufacturing Technology, 61(2): 703–723. doi: 10.1016/j.cirp.2012.05.00
[8] Inspektor, A. Salvador, P.A. (2014) Architecture of PVD coatings for metalcutting applications: A review. Surface & Coatings Technology 257138–153
[9] Rech, J. (2006) Influence of cutting edge preparation on the wear resistance in high speed dry gear hobbing. In Wear. Vol. 261, Issues 5–6, pp. 505-512.
[10] Dana, M.; Zetek, M. & Schorník, V. (2016). Effect of Cutting Edge Geometry on Cutting Tool Life when Drilling Inconel 718, Proceedings of the 26th DAAM International Symposium, pp.0709-0714, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-07-5, ISSN 1726-9679, Vienna, Austria DOI: 10.2507/26th.daaam.proceedings.
[11] Vopat, T.; Kuruc, M.; Simna, V.; Zaujec, R. & Peterka, J. (2017). Cutting Edge Microgeometry and Preparation Methods, Proceedings of the 28th DAAAM International Symposium, pp.0384-0391, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-11-2, ISSN 1726-9679, Vienna, Austria DOI: 10.2507/28th.daaam.proceedings.
[12] Adoberg, E.; Podgurski, V.; Peetsalu, P.; Lind, L.; Mikli, V.; Hvizdos, P.; Kulu, P. (2012) The effect of surface pre-treatment and coating post-treatment to the properties of TiN coatings. Estonian Journal of Engineering, 18(3): 185–192. doi: 10.3176/eng.2012.3.03
[13] Vozar, M.; Patoprsty, B; Vopat, T. & Peterka, J. (2019). Overview of Methods of Cutting Edge Preparation, Chapter 20 in DAAAM International Scientific Book 2019, pp.251-264, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-24-2, ISSN 1726-9687, Vienna, Austria DOI: 10.2507/daaam.scibook.2019
[14] Bräuer, G., Szyszka, B., Vergöhl, M., Bandorf, R. (2010). Magnetron sputtering - Milestones of 30 years. Vacuum, 84(12), pp. 1354–1359
[15] Anders, A. (2017). Tutorial: Reactive high power impulse magnetron sputtering (R-HiPIMS). Journal of Applied Physics, 21(17), p. 171101
[16] Bohlmark, J., Alami, J., Christou, C., Ehiasarian, A. P. and Helmersson, U. (2005). Ionization of sputtered metals in high power pulsed magnetron sputtering. Journal of Vacuum Science & Technology, 2005, Vol.23, No.1, pp 18–22, ISSN 0734-2101
[17] Alami, J., Eklund, P., Andersson, J. M., Lattemann, M., Wallin, E., Bohlmark, J., Persson, P., Helmersson, U. (2007). Phase tailoring of Ta thin films by highly ionized pulsed magnetron sputtering. Thin Solid Films, 2007, Vol.515, No.7–8, pp 3434–3438, ISSN 00406090
[18] Sarakinos, K., Alami, J., Wuttig, M. (2007). Process characteristics and film properties upon growth of TiO x films by high power pulsed magnetron sputtering. Journal of Physics D: Applied Physics, 2007, Vol.40, No.7, pp 2108–2114, ISSN 0022-372
[19] Engwall, A. M., Shin, S. J., Bae, J., Wang, Y. M. (2019). Enhanced properties of tungsten films by high-power impulse magnetron sputtering. Surface and Coatings Technology, 2019, Vol.363, pp 191–197, ISSN 02578972

[20] Samuelsson, M., Lundin, D., Jensen, J., Raadu, M. A., Gudmundsson, J. T., Helmersson, U. (2010). On the film density using high power impulse magnetron sputtering. Surface and Coatings Technology, 2010, Vol.205, No.2, pp 591–596, ISSN 02578972

[21] Ehiasarian, A.P., Wen, J. G., Petrov, I. (2007). Interface microstructure engineering by high power impulse magnetron sputtering for the enhancement of adhesion. Journal of Applied Physics, 2007, Vol.101, No.5, ISSN 0021-8979

[22] Greczynski, G., Lu, J., Jensen, J., Bolz, S., Kolker, W., Schiffers, Ch., Lemmer, O., Greene, J. E., Hultman, L. (2014) A review of metal-ion-flux-controlled growth of metastable TiAlN by HIPIMS/DCMS co-sputtering. Surface and Coatings Technology, 2014, Vol.257, pp 15–25, ISSN 02578972

[23] Bohlmark, J., Östbye, M., Lattemann, M., Ljungcrantz, H., Rossell, T., Helmersson, U. (2006) Guiding the deposition flux in an ionized magnetron discharge. Thin Solid Films, 2006, Vol.515, No.4, pp 1928–1931, ISSN 00406090

[24] ISO 3497. (1990) Measurement of Coating Thickness of Metallic Coatings, X-Ray Spectrometric Methods. Available online: https://www.iso.org/standard/8850.html (accessed on 12 May 2022)

[25] Landeta, J.F.; Valdivielso, A.F.; López de Lacalle, L.N.; Girot, F.; Pérez Pérez, J.M. (2015) Wear of form taps in threading of steel cold forged parts. Journal of Manufacturing Science and Engineering, 137(3): 031002-031002-11. doi: 10.1115/1.4029652

[26] Korhonen, H. , Koistinen, A. & Lappalainen, R. (2018): Improvements in the thread cutting torque for a 6082-T6 aluminum-based alloy with tapping tools utilizing diamond coating, Machining Science and Technology, DOI: 10.1080/10910344.2017.1402930

[27] Reiter, A.E., Brunner, B., Ante, M., Rechberger, J. (2006). Investigation of several PVD coatings for blind hole tapping in austenitic stainless steel. Surface and Coatings Technology, 200(18-19), pp. 5532–5541. https://doi.org/10.1016/j.surfcoat.2005.07.100

[28] Píška, M.; Polzer, A. (2012) On the advanced PVD coatings for threading in austenitic steel. Proceedings of the 23rd DAAAM International Symposium on Intelligent Manufacturing and Automation, October 24–27, Zadar, Croatia. 23(1): 0831–0834.

[29] Píška, M.; Sliwkova. (2014). On The Cutting Performance of Coated HSS Taps when Machining of Austenitic. Technological Engineering. Volume XI, number 1/2014 ISSN 1336 – 5967, pp. 28-32. DOI: 10.2478/teen-2014-0006

[30] ISO 3002-4 (Basic Quantities in Cutting and Grinding - Part 4: Forces, energy, power).