Analysis of the influence of the dressing feed rate of a grinding wheel with sintered corundum on the surface roughness of AMS6308 steel after carburising in plunge grinding

Analiza wpływu prędkości posuwu obciągania ściernicy z domieszką korundu spiekanego na chropowatość powierzchni stali AMS6308 po nawęglaniu w procesie szlifowania wgłębnego

WITOLD HABRAT
MARCIN SAŁATA
TOMASZ ORDON *

DOI: https://doi.org/10.17814/mechanik.2025.8-9.7

The influence of the grinding wheel dressing speed on the surface roughness of AMS6308 steel after carburising during plunge grinding was investigated. A single-grain CVD diamond dresser and a grinding wheel with a 50% admixture of sintered corundum were applied. An increase in the dressing feed rate resulted in an increase in the surface roughness parameters after grinding.
KEYWORDS: plunge grinding, carburising, single-grain dresser, surface roughness

Badano wpływ prędkości obciągania ściernicy na chropowatość szlifowanej powierzchni stali AMS6308 po nawęglaniu podczas szlifowania wgłębnego. Zastosowano jednoziarnisty obciągacz słupkowy z diamentu CVD oraz ściernicę z 50% domieszką korundu spiekanego. Wzrost posuwu obciągania powodował wzrost parametrów chropowatości powierzchni po szlifowaniu.
SŁOWA KLUCZOWE: szlifowanie wgłębne, nawęglanie, obciągacz jednoziarnisty, chropowatość powierzchni

Pyrowear® 53 steel (AMS6308) is intended for the production of components in drive systems exposed to high temperatures and subjected to heavy loads. It has been successfully applied, for instance, in highly loaded gears of aerospace transmissions [1]. After carburising and hardening, the surface attains very high hardness, which significantly enhances wear resistance [2]. Thermochemical treatment causes deformations of precise geometrical features of the workpiece, which necessitates finishing through grinding [3,4]. The high hardness of the carburised layer renders machining difficult and requires considerable precision as well as an understanding of the mechanisms occurring during cutting. Other researchers [5,6] have also investigated the grinding of hard-to-machine materials, including cemented carbides. In their studies, the influence of grinding speed and feed rate was analysed, demonstrating that these parameters exert a significant effect on the surface roughness. Furthermore, attention was drawn to problems occurring during grinding processes, such as grinding burns. Only a limited number of publications take into account the influence of the dressing feed rate on the formation of surface roughness.

There is a lack of publications concerning the formation of the active surface of grinding wheels with a sintered corundum admixture using a single-grain stick dresser, which is characterised by a constant width throughout its service life, thus ensuring a constant coverage ratio during dressing.

Materials and methods

The experimental setup for plunge grinding was built on the basis of a three-axis CNC cylindrical grinding machine RS 600 manufactured by Geibel & Hotz. The machine is equipped with three numerically controlled axes – X, Z, and the rotary axis B.

Surface roughness measurements were carried out using a MarSurf XR20 profilometer with a GD 120 traverse unit and a measuring tip with a stylus length of 35 mm, a stylus tip radius of 2 μm, and a stylus apex angle of 90°. The measurement procedure was developed in accordance with PN-EN ISO 4288:2011. The evaluation length was 4.8 mm, with a cut-off wavelength $\lambda c = 0.8$ mm. Measurements were performed in three cross-sections, and the mean value was used for the analysis.

For the grinding process, a grinding wheel with dimensions 400 × 50 × 127 mm, type 5NQ 80J 10VS3P, was employed. This is a rectangular-profile wheel made of fused alumina with a 50% admixture of sintered corundum in a vitrified bond. The wheel diameter is 400 mm, and its width is 50 mm. Due to the limited number of test specimens, grinding was carried out with a wheel width of 10 mm.

* Dr hab. inż. Witold Habrat – witekhab@prz.edu.pl, https://orcid.org/0000-0002-9010-8175, Politechnika Rzeszowska, Rzeszów, Polska
Dr inż. Marcin Sałata – msalata@prz.edu.pl, https://orcid.org/0000-0002-2338-4380, Politechnika Rzeszowska, Rzeszów, Polska
Mgr inż. Tomasz Ordon – tomasz.ordon@prattwhitney.com, Pratt & Whitney Rzeszów S.A.

Plunge grinding was carried out on workpieces in the form of cylindrical bars with a diameter of ⌀22.5 mm and a length of 111 mm. The material used was AMS6308 steel after carburising to an average depth of at least 1 mm, with a hardness of approximately 63 HRC. The chemical composition of the steel was as follows: C – 0.11%, Mn – 0.4%, Si – 0.9%, Cr – 1.0%, Ni – 2.0%, Mo – 3.25%, Cu – 2.0%, V – 0.1%, Fe – balance.

The experimental investigations were planned using the Design-Expert software. A central composite orthogonal design (FCD) for two independent variables was adopted. The variable parameters were as follows:

- Grinding speed; v_s = 25 ÷ 35 m/s,
- Dressing feed rate f_{ad} = 0,06 ÷ 0,20 mm/rev.

The constant parameters of the counter-directional grinding process were: grinding width ae = 10 mm, grinding depth a_p = 0,1 mm, grinding feed rate v = 0,25 mm/min, and the ratio of grinding wheel speed to workpiece speed v_s /v_w = 100.

For the formation of the active surface of the grinding wheel, a single-grain dresser type AF21-C665D manufactured by Dr. Kaiser was employed (fig. 1). The dresser has the form of a rectangular-section stick (0,6 × 0,6 mm) in which a diamond grain produced using CVD (Chemical Vapour Deposition) technology is embedded. The dresser is characterised by high hardness and wear resistance, which enables precise shaping and renewal of the grinding wheel active surface. Owing to the use of diamond in a metallic matrix, the tool ensures dimensional stability and long service life, while simultaneously allowing the achievement of appropriate sharpness and geometry of the abrasive grains during the dressing process.

Results, analysis and conclusion

In the first stage of the study, based on the obtained results, the significance of the input factors was determined, and mathematical model equations describing the variation of the roughness parameters *Ra* and *Rz* as functions of the dressing feed rate f_{ad} and the grinding speed were developed. The following relationships were obtained:

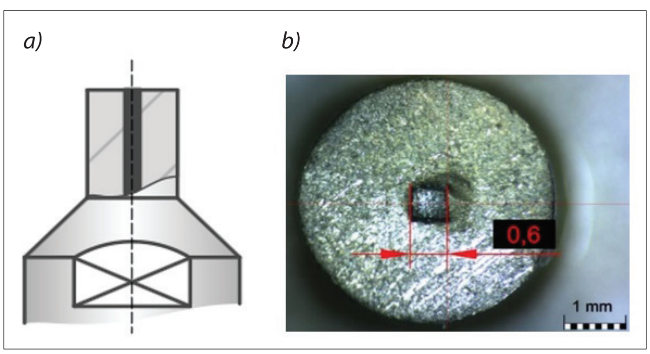

Fig. 1. AF21-type dresser: *a*) schematic arrangement of the CVD diamond stick in the dresser, *b*) microscope image – top view with the diamond stick clearly visible

Rys. 1. Obciągacz typu AF21: a) schemat ułożenia sztabki diamentowej CVD w obciągaczu, *b*) obraz z mikroskopu – widok z góry z wyraźnie widoczną sztabką diamentu

$$Ra = 0{,}118 + 2{,}134 \cdot f_{ad} - 5{,}997 \cdot f_{ad}^2 \quad (1)$$

$$Rz = 1{,}140 + 18{,}223 \cdot f_{ad} - 55{,}189 \cdot f_{ad}^2 \quad (2)$$

The coefficient of determination for model (1) was R^2 = 0,84, while for model (2) it was R^2 = 0,81.

A graphical interpretation of the relationships between technological parameters, such as grinding speed v_s and dressing feed rate f_{ad}, and surface roughness parameters *Ra* and *Rz* is presented in figs. 2–3. Analysis of the surface roughness parameter *Ra* revealed a statistically significant dependence of its value on the dressing feed rate of the grinding wheel. It was found that *Ra* values ranged from 0,227 to 0,319 µm, indicating that differences between individual experiments were noticeable and significant. The range of this parameter for all analysed trials was 0,093 µm, confirming that the variability of *Ra*

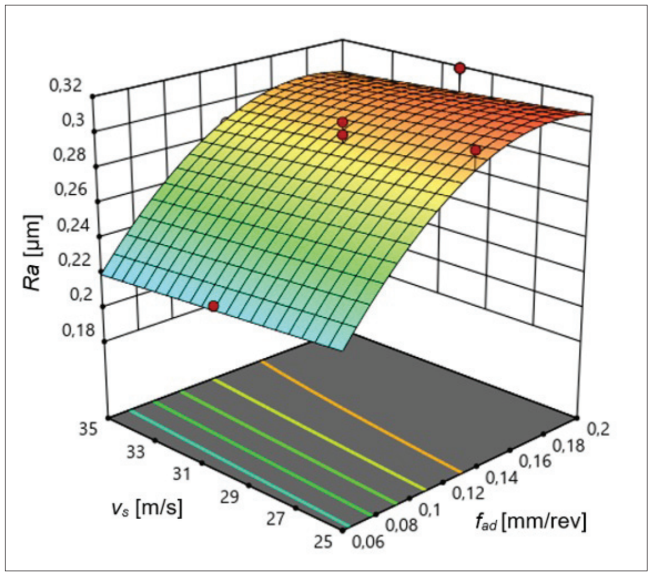

Fig. 2. Effect of grinding speed v_s and dressing feed rate f_{ad} on the surface roughness parameter *Ra*

Rys. 2. Wpływ prędkości szlifowania v_s oraz posuwu obciągania ściernicy f_{ad} na parametr chropowatości powierzchni *Ra*

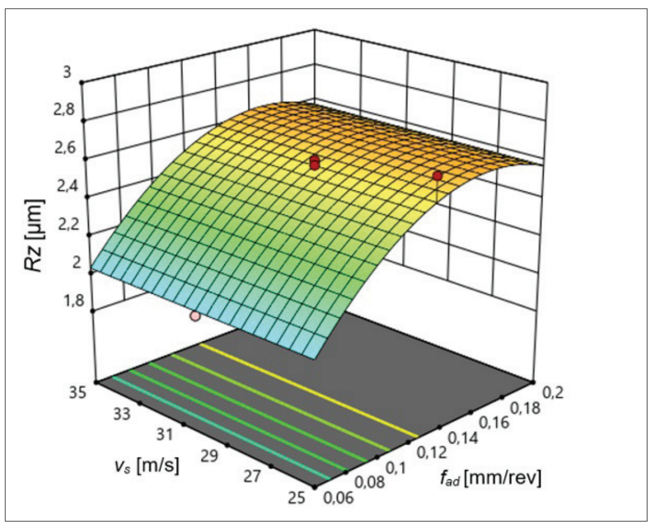

Fig. 3. Effect of grinding speed v_s and dressing feed rate f_{ad} on the surface roughness parameter *Rz*

Rys. 3. Wpływ prędkości szlifowania v_s oraz posuwu obciągania ściernicy f_{ad} na parametr chropowatości powierzchni *Rz* is relatively wide and depends on the selected machining parameters.

Similar conclusions were drawn from the analysis of the surface roughness parameter Rz. In this case, the parameter values ranged from 2,009 to 2,707 µm, with clear variations observed between individual trials. The range of *Rz* values reached 0,698 µm.

Based on the graphical interpretation presented in figs. 2–3, it was observed that the grinding speed v_s does not exert a statistically significant effect on the surface roughness parameters. This conclusion is further supported by the analysis of variance (ANOVA), in which the p-value for the grinding speed v_s was 0,3544 for model (1) and 0,282 for model (2), both being substantially higher than the adopted significance level of $p = 0,05$.

A statistically significant effect on the surface roughness parameters was, however, demonstrated for the dressing feed rate f_{ad}, indicating the dominant role of this factor in shaping the surface quality after grinding. The p-value for the dressing feed rate f_{ad} was <0,0001, confirming its high statistical significance and the considerable influence of this factor on the determination of the surface roughness parameters.

In summary, based on the conducted investigations and developed models, it can be concluded that, overall, the only factor exerting a significant influence on the surface roughness parameters *Ra* and *Rz* is the dressing feed rate f_{ad}.

In the second stage of the study, based on the obtained results, detailed relationships between the dressing feed rate f_{ad} and surface roughness parameters were developed. The analysis included roughness parameters such as *Ra, Rz, Rv, Rp, Rt, RSk, RKu, Rdq*, and *RSm*, while selected parameters were presented for graphical interpretation of the results (figs. 4–6). The scatter of the results was adopted as a measure of error.

Analysis of the surface roughness parameter *Ra* (fig. 4) showed that its minimum value was 0,23 µm, while the maximum reached 0,32 µm. This indicates that an increase in the dressing feed rate from 0,06 to 0,20 mm/rev results in a 39,1% increase in surface roughness.

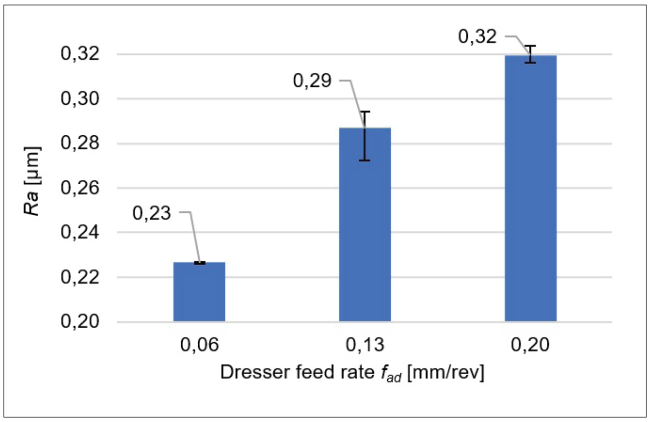

Fig. 4. Effect of the dressing feed rate f_{ad} on the surface roughness parameter *Ra*
Rys. 4. Wpływ posuwu obciągania ściernicy f_{ad} na parametr chropowatości powierzchni *Ra*

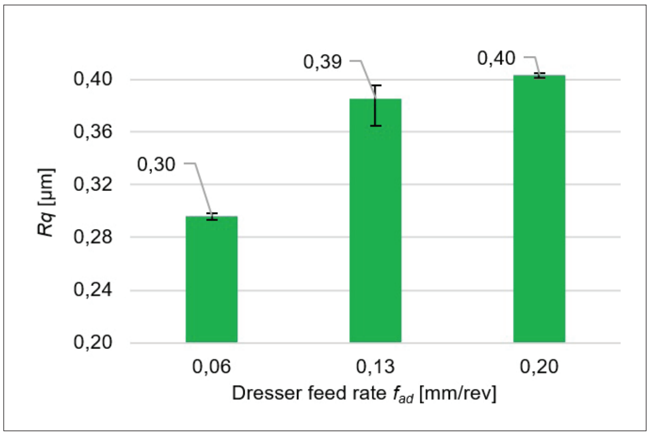

Fig. 5. Effect of the dressing feed rate f_{ad} on the surface roughness parameter *Rq*
Rys. 5. Wpływ posuwu obciągania ściernicy f_{ad} na parametr chropowatości powierzchni *Rq*

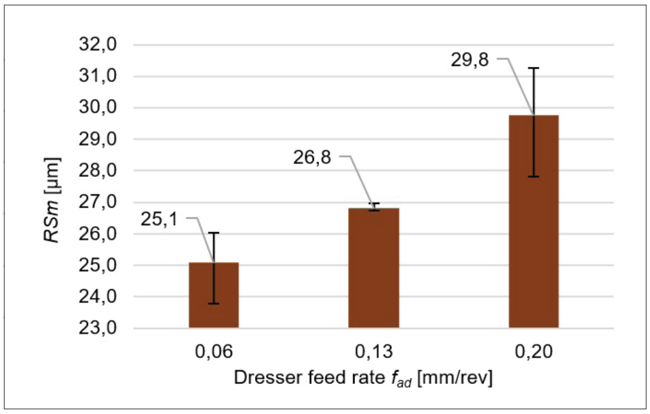

Fig. 6. Effect of the dressing feed rate f_{ad} on the surface roughness parameter *RSm*
Rys. 6. Wpływ posuwu obciągania ściernicy f_{ad} na parametr chropowatości powierzchni *RSm*

Analysis of the surface roughness parameter *Rq* (fig. 5) showed that its minimum value was 0.30 µm, while the maximum reached 0,40 µm. This indicates that an increase in the dressing feed rate from 0,06 to 0,20 mm/rev results in a 33,3% increase in surface roughness. The *Rq* parameter characterises the root mean square height of surface deviations relative to the mean line of the profile, with higher values indicating steeper and more pronounced irregularities than *Ra*. The observed increase in *Rq* with increasing dressing feed rate reflects the intensified interaction of the tool with the surface and the formation of more prominent irregularities during the grinding process.

The study showed that the surface roughness parameter *RSm* (fig. 6) had a minimum value of 25 µm and a maximum of 30 µm. This indicates that an increase in the dressing feed rate leads to an approximately 20% increase in the mean spacing between successive peaks and valleys of the surface profile. The *RSm* parameter characterises the mean width of the profile and provides information on the frequency of surface irregularities, with higher values indicating sparser and more elongated irregularities.

In summary, the results obtained during the internal grinding of carburised AMS6308 steel demonstrated a clear influence of the dressing feed rate of the sintered corundum-containing grinding wheel on the surface roughness parameters when using a single-grain CVD diamond stick dresser. This phenomenon can be explained by the fact that a higher dressing feed rate leads to more intensive shaping of the active grinding wheel surface, resulting in larger and more varied irregularities depending on the load on individual grains of both electrocorundum and sintered corundum. Statistical analysis indicated that the grinding speed v_s had no significant effect on the roughness parameters, whereas the dressing feed rate showed a high level of significance, confirming its dominant role in determining surface quality during internal grinding.

This study was supported by the Ministry of Education and Science under the Implementation Doctorates Project (4th edition – Doktorat Wdrożeniowy)

REFERENCES

[1] R. Fularski i R. Filip, „The Effect of Chip Binding on the Parameters of the Case-Hardened Layer of Tooth Surfaces for AMS 6308 Steel Gears Processed by Thermochemical Treatment", *Materials 2021, Vol. 14, Page 1155*, t. 14, nr 5, s. 1155, mar. 2021, doi: 10.3390/MA14051155.

[2] A. Wojtyczka i B. Iżowski, „Microstructure and hardness of Pyrowear 53 steel after low-pressure vacuum carburizing at 921°C", Advances in Manufacturing Science and Technology, t. 44, nr 4, s. 109–112, grudz. 2020, doi: 10.2478/AMST-2019-0020.

[3] L. Wang, L. Yang, L. Wang, X. Tang, i G. Liu, „Influence mechanism of grinding surface quality of 20CrMnTi steel on contact failure", Scientific Reports 2024 14:1, t. 14, nr 1, s. 1–11, cze. 2024, doi: 10.1038/s41598-024-64320-0.

[4] J. Sawicki, B. Kruszyński, i R. Wójcik, „The influence of grinding conditions on the distribution of residual stress in the surface layer of 17crni6-6 steel after carburizing", *Advances in Science and Technology. Research Journal*, t. 11, nr 2, s. 17–22, cze. 2017, doi: 10.12913/22998624/67671.

[5] Habrat, W.F. "Effect of Bond Type and Process Parameters on Grinding Force Components in Grinding of Cemented Carbide". *Procedia Eng*. 2016, 149, 122–129, https://doi.org/10.1016/j.proeng.2016.06.646.

[6] Sałata, M.; Babiarz, R.; Kęcik, K. "Detection of Defects in Solid Carbide Cutting Tools During Creep-Feed Flute Grinding (CFG) Using Recurrence Analysis". *Materials* 2025, 18, 2743 https://doi.org/10.3390/ma18122743