Rocznik Ochrona Środowiska

Volume 26 Year 2024 ISSN 2720-7501 pp. 629-637

https://doi.org/10.54740/ros.2024.055 open access

Received: November 2024 Accepted: November 2024 Published: December 2024

Methods of Reducing Burrs in the Process of Cutting and Blanking Metal Materials

Łukasz Bohdal[1], Agnieszka Kułakowska[2], Robert Tomkowski[3], Hamzah Ssekiunga Ssemakula[4]*

[1]Department of Mechanical Engineering, Koszalin University of Technology, Koszalin, Poland
https://orcid.org/0000-0002-8085-9530
[2]Department of Mechanical Engineering, Koszalin University of Technology, Koszalin, Poland
https://orcid.org/0000-0001-5506-5440
[3]Department of Production Engineering, Manufacturing and Metrology Systems,
KTH Royal Institute of Technology, Stockholm, Sweden
https://orcid.org/0000-0003-3056-781X
[4]Department of Production Engineering, Manufacturing and Metrology Systems,
KTH Royal Institute of Technology, Stockholm, Sweden

**corresponding author's e-mail: lukasz.bohdal@tu.koszalin.pl*

Abstract: In metal cutting and blanking processes, one of the primary technological challenges is the formation of burrs on the surfaces of cut parts, especially in thin materials. Many companies face the issue of excessive waste due to burr formation after cutting. Understanding the causes of this defect is complex. This paper presents the current state of knowledge and the authors' research on reducing burr occurrence on cut surfaces. The conditions for achieving a high-quality cut edge were determined through numerical and experimental studies. With the increase of the rake angle in shear-slitting, the burr height decreases. When cutting with trimming, the cutting clearance value should be within h_c = 1-3% of the material thickness. When blanking, the cutting clearance should be less than 10% of the thickness of the material being cut. The findings support selecting optimal process conditions to minimise waste after cutting.

Keywords: cutting, blanking, burr, waste, numerical and experimental analysis

1. Introduction

Optimising production processes and responsibly using resources are essential to modern company operations. Efficient, modern production plants should aim to minimise the impact of their processes on soil, air, and water. Increasingly, companies are demonstrating their environmental impact through ecological balance assessments. In cutting processes, one of the main challenges is excessive waste generation on production lines, often resulting from improper process implementation, incorrect parameter selection, or worn tools (Arslan 2020, Bohdal 2022). Burr formation is one of the main macro-geometrical defects affecting machined metal surfaces. Burrs are hard, sharp, raised edges formed along the cut edge during blanking and cutting processes (Barik 2018) (see Fig. 1). The deburring process significantly increases operation time and costs (Cao 2016), leading many companies to dispose of the product as waste.

Current research focuses on defining burrs, understanding their causes, and assessing their impact on product quality (Cavusoglu 2017, Demmel 2017, Dems 2023). Burrs on sheared edges reduce product quality, complicate machining and assembly, and may cause interlayer short circuits in electric motor cores (Dems 2023). Deburring can contribute up to 30% of the total cost of finished parts, and secondary finishing is challenging to automate (Poór 2021). Burr height on the cut surface indicates cutting process efficiency, directly affecting product quality. Therefore, minimising burr formation during production by selecting appropriate process parameters is crucial (Ghadbeigi 2020).

Based on a review of current knowledge, burr height can be reduced mainly by optimising cutting clearance and cutting tool geometry (Han 2022, Bohdal 2022). Cutting clearance refers to the gap between the punch and die in punching processes or between blades in guillotine cutting or shear-slitting (He 2019). Tool geometry can be adjusted by modifying the rake angle or rounding the cutting edge radius (Husson 2008, Bohdal 2020). However, these parameters require tailored adjustments for different steel types and thicknesses, creating challenges on production lines. This paper assesses the impact of cutting clearance and tool geometry on burr formation on cut surfaces.

Based on the state of knowledge and own research, the conditions for implementing the process that allows for the reduction of burrs in the cutting process were determined. The paper is organised as follows:
a) simulation studies (influence clearance on burrs height), b) experimental studies (influence clearance on burrs height), c) experimental studies (influence the optimal selection of cutting tool geometry on burrs height), d) proposal of a new solution.

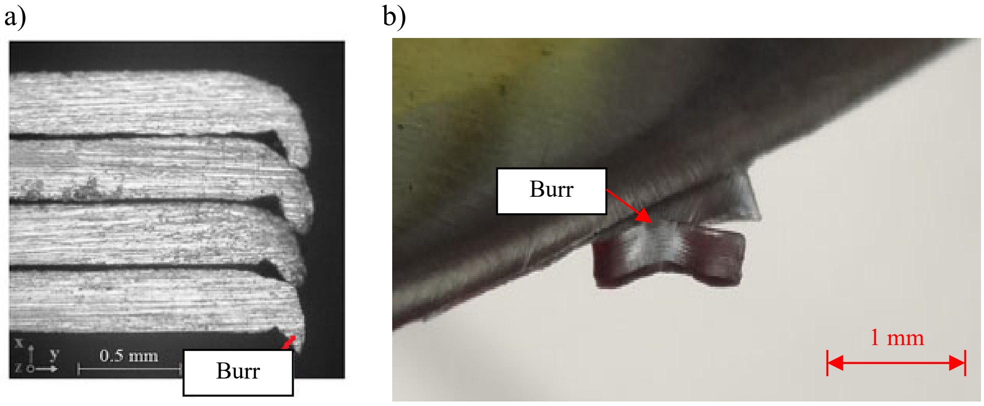

Fig. 1. a) The influence of burrs on potential interlayer short-circuit points in transformer cores (Hamzehbahmani 2016), b) Example of an irregular burr on a cut edge

2. Reduction of Burrs Through Optimal Cutting Clearance Selection

Cutting clearance is a key parameter that determines the height of the burr on the cutting surface of qorkpiece. However, its value also depends on the cutting speed. There are works in the literature in which theauthors analyse the effect of cutting clearance on the quality of the cut edge. The authors of the work (Wiedenmann 2009) analysed the cutting process of electrical steel with a thickness of t = 1.4 mm. The influence of the clearance value on the quality of the cut edge of elements in the range of h_c = 5-20%t during the cutting of holes with a diameter of 10 mm was investigated. The analysis revealed that as cutting clearance increases, the rounding and cracking zones widths also increase while the smooth zone decreases. These findings align with conclusions from Gréban (2007), who investigated how material microstructure and process parameters impact cut edge quality by measuring the width of individual zones on the surface. The studies indicated that burr height is more influenced by cutting clearance and material type than by the deformation rate of the material. Additionally, the rounding zone is strongly affected by cutting clearance and tool geometry, while the smooth and cracking zones depend largely on the mechanical properties of the sheet metal.

In this work, different thicknesses of cut sheets were used in the analyses. As the analysis of the state of knowledge has shown, the burr height depends not only on the processing parameters but also on the thickness of the cut sheet. Thin sheets with a thickness below t = 0.5 mm are more susceptible to the negative effect of the bending moment than sheets with greater thicknesses, e.g. t = 4 mm. The bending moment extends the plastic flow phase and causes burr growth. Therefore, it is important to determine the effect of, among others, the cutting clearance on the burr height depending on the sheet thickness. Knowledge on this subject is limited. The variable thickness of the sheet metal is not taken into account.

In this paper, we have proposed a method for determining the optimal cutting clearance using FEM modelling and experimental studies. For this purpose, a numerical model was bored in the LS-Prepost system (Fig. 2).

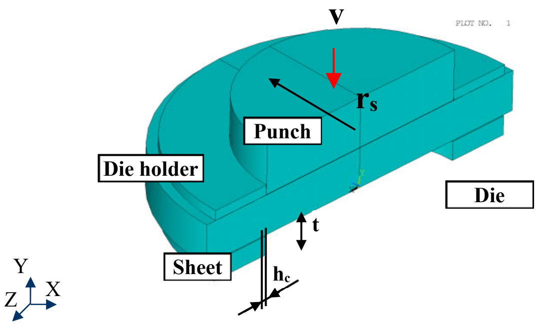

Fig. 2. Geometric model of the blanking process: cross-sectional view: r_s – punch radius, h_c – blanking clearance, t – sheet thickness, v – punch speed

The simulation results of the blanking process for thick sheets, accounting for the curvature of the cutting line and the effect of cutting clearance on cut edge quality, are presented in Figures 3-5. The tests utilised 1018 steel, and the material description was modelled using the Cowper-Symonds elastic/viscoplastic model. The punch speed was set v = 20 mm/s, based on industrial device data from EMET sp. z o.o. from Szczecinek, with which the authors cooperate with a punch radius of r_s = 11 mm, and a sheet thickness of t = 4 mm (Fig. 2). Simulations were performed for various cutting clearance values: h_c = 0%t, h_c = 5%t, h_c = 10%t, and h_c = 15%t, following the scope of regulation on the industrial device TRUMPF TruPunch.

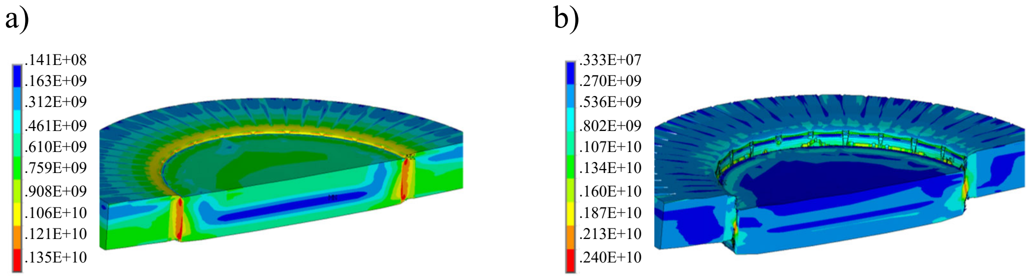

Fig. 3. Distribution (maps) of equivalent stresses in the sheet metal cross-section: a) plastic flow phase for the punch displacement w = 0.5 mm, b) cracking phase for w = 1.7 mm (h_c = 0%t)

Fig. 3 shows the distribution of Huber-Mises equivalent stresses for the clearance h_c = 0%t. In the initial phase of the cutting process, the highest stress values were observed in the contact zone between the punch and die with the cut material. During the plastic flow phase, maximum stresses were distributed across the entire thickness of the material until cracking was initiated. The cracking process began at the lower part of the die, ultimately leading to the complete material separation. Fig. 4 shows the influence of the clearance on the values of maximum equivalent stresses in the individual process phases, measured in the area of contact between the punch and the material in the fracture zone.

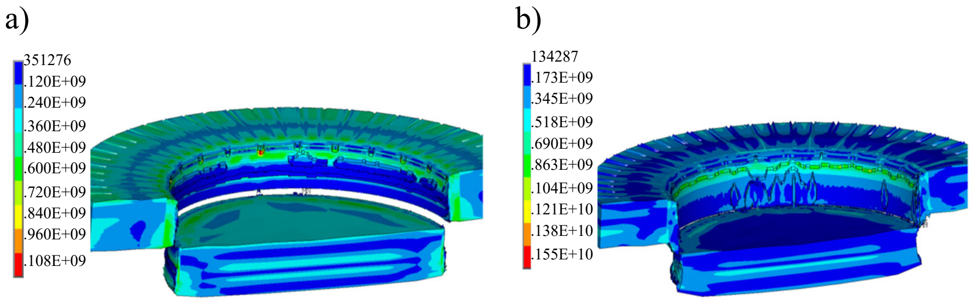

Fig. 4. The influence of clearance on the distribution of equivalent stresses in the final phase of the process:
a) h_c = 0%t, b) h_c = 15%t

The simulation and experimental studies demonstrate that the clearance between the punch and the die significantly influences the speed of material separation. For the case of punching, when the clearance value is h_c = 0%t, the material was completely separated for the displacement of the punch into the material of w = 50%t, while for the clearance h_c = 15%t, the displacement value was w = 82%t. An increase in cutting clearance resulted in a wider crack zone and greater rollover on the surface of the cut material. As the clearance increased, there was a corresponding delay in the moment of complete material separation, which led to an increase in the height of the burrs formed at the cut edge (as shown in Fig. 5).

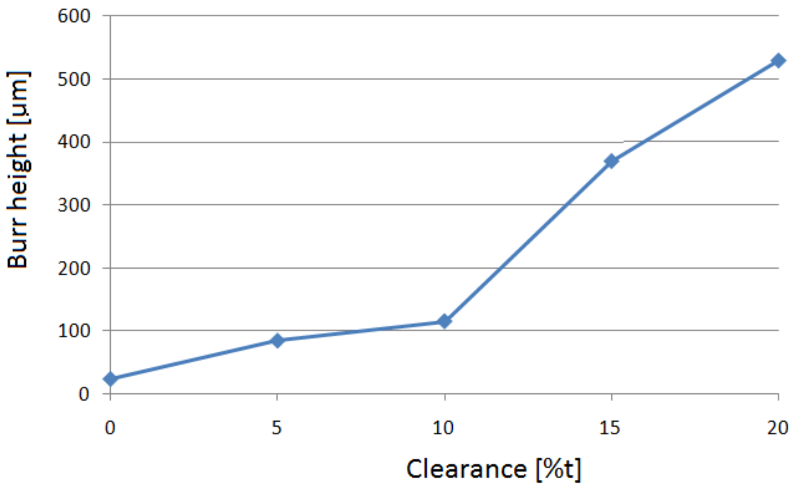

Fig. 5. The influence of clearance on the burr height

A notable increase in burr height occurs after surpassing the clearance value of h_c = 10%t. For a sheet thickness of t = 4 mm, this value represents a critical threshold that minimises the increase in bending moment and excessive material flow during the cutting process. Due to the increase in contact pressures for clearances in the range of h_c = 0-5%t and possible acceleration of cutting tool wear, the clearance value should be about h_c = 10%t.

Further research was conducted on thin sheets with t = 0.3 mm thickness. For these thinner materials, the selection of cutting clearance is critically dependent on the cutting speed. The experiments used circular shears and used ET 110-30LS electrical steel as the test material.

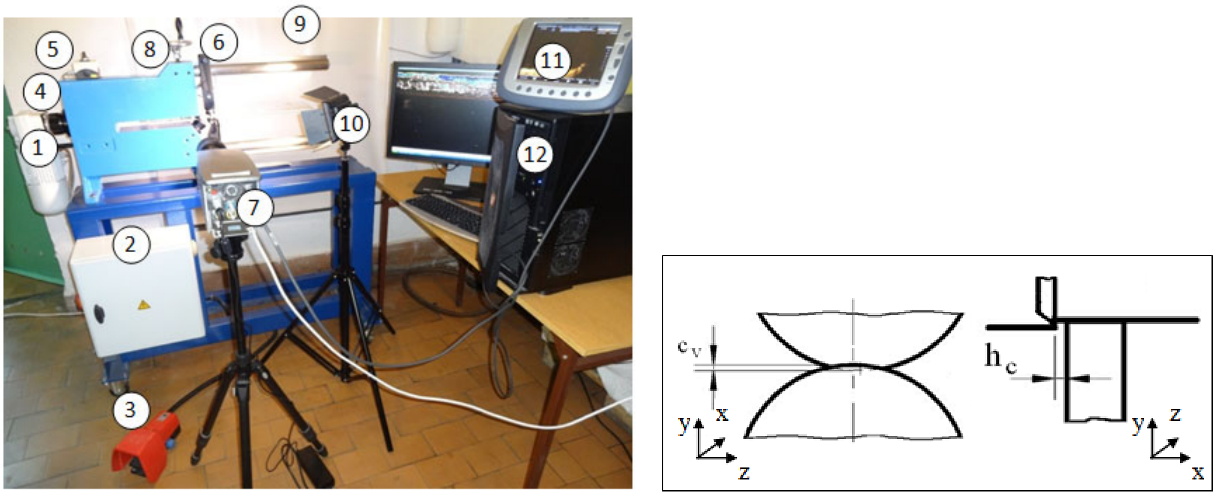

Fig. 6. Experimental test stand for thin sheets cutting: 1 – engine, 2 – electrical system, 3 – drive pedal, 4 – threaded socket with a scale for adjusting the cutting clearance, 5 – cutting speed regulator, 6 – sheet stabiliser (needle), 7 – high-speed camera, 8 – knife overlap regulator, 9 – scale for determining the diameter of cut discs for curvilinear outlines, 10 – LED lamp, 11 – auxiliary screen for recording and analysis, 12 – computer workstation for archiving measurement data

Table 1. The ranges of the variability of the studied factors

Horizontal clearance, h_c	0.02-0.1 mm
Vertical clearance, c_v	0.1 mm
Slitting velocity, v	3-24 m/min
Rake angle, α	5-40°

The research results indicate that utilising clearances exceeding h_c = 0.06 mm causes a significant increase in burr height, regardless of the cutting speed (Fig. 7). This may be due to a decrease in the stability of the flow and cracking processes, which results in a reduction in the width of the sliding fracture while simultaneously increasing the width of the separation fracture and the height of the burr. When the clearance exceeds the allowable limits, it leads to an excessive concentration of the bending moment within the cutting zone. This not only exacerbates the formation of burrs but also can negatively affect the overall quality and integrity of the cut edge.

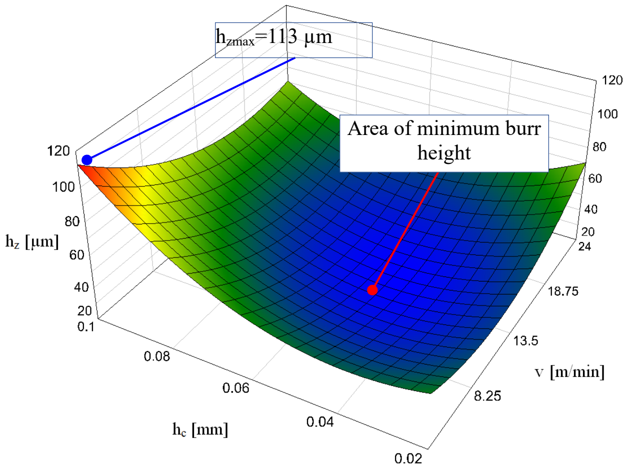

Fig. 7. Influence of cutting speed v and clearance h_c on burr height

For clearances exceeding h_c = 0.08 mm, the height of the burr becomes excessively large, which can lead to issues on the production line at all analysed cutting speeds. This increase in burr height further contributes to greater rollover of the edges, adversely affecting the quality of the finished products. By reducing the clearance value to h_c = 0.04 mm, it is possible to increase the cutting speed to v = 24 m/min while still achieving an acceptable burr height. This optimisation enhances cutting efficiency and ensures that the cut edges' quality meets the required standards, illustrating the importance of precisely adjusting clearance settings in the cutting process.

3. Reduction of Burrs Through Optimal Selection of Cutting Tool Geometry

Selecting the appropriate geometry of cutting tools in cutting processes is complex. Tool geometry significantly affects cutting forces, contact pressure distributions, and tool durability. Previous studies, such as those by Weiss (2017) and Dems (2023), highlight that the influence of tool geometry on product quality is interdependent with other process parameters, including cutting clearance and cutting speed. In this paper, the authors conducted analyses to evaluate the effect of the upper knife rake angle (α) on burr height. The experiments assessed how varying the rake angle interacts with different cutting clearance values (see Table 1). The research findings are illustrated in Figure 8.

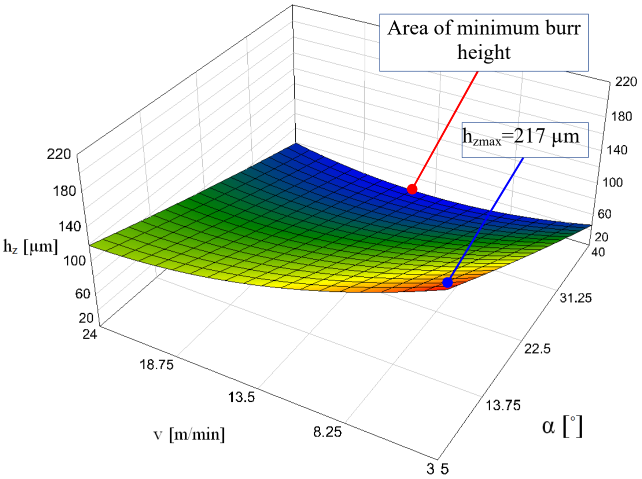

Fig. 8. Influence of cutting speed v and rake angle α on burr height

As the rake angle increases, the burr height decreases, demonstrating a clear relationship between tool geometry and cutting quality. From the perspective of process efficiency, when operating at the maximum cutting speed of v = 24 m/min, the optimal rake angle should be maintained within the range of α = 30-40° (Fig. 8). If the clearance value is less than h_c = 0.04 mm, it is advisable to use small rake angles in the range of α = 5-18°. When using a clearance above h_c = 0.06 mm, it is beneficial to increase the rake angle. A larger rake angle decreases the bending moment in the cutting area due to a smaller contact zone between the knives and the material, allowing the material to crack earlier in the cutting process. Conversely, a reduced rake angle results in a wider deformation zone and greater shifting of the material fibers.

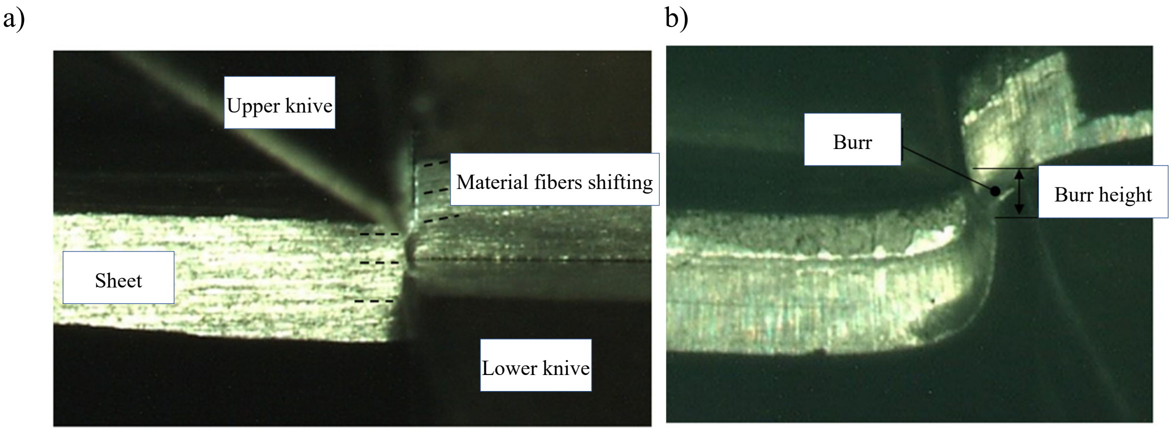

Fig. 9. Influence of rake angle α on burr height: a) α = 40°, b) α = 7°

The longer duration of the material's plastic flow phase leads to the crack line being positioned further away from the cutting edges of the tools. This increased distance results in a greater bending moment within the sheet metal cross-section, contributing to the formation of burrs at the cut edges. The extended plastic deformation allows more material to flow and accumulate at the edges, which not only raises the height of the burr but also can adversely affect the overall quality of the cut surface.

4. A New Method for Removing Burrs from the Cut Surface During the Cutting Process

Based on their research, the authors of this paper developed a new method for removing burrs during the cutting process. Based on the developed numerical model in the LS-Prepost program, analyses of the influence of cutting tool geometry and cutting clearance on the quality of the cut edge were carried out. Based on the research results, a new tool geometry was proposed in which its especially inclined cutting edge performs the process of trimming a fragment of the cut surface of a material with the burr (Figs. 10 and 11).

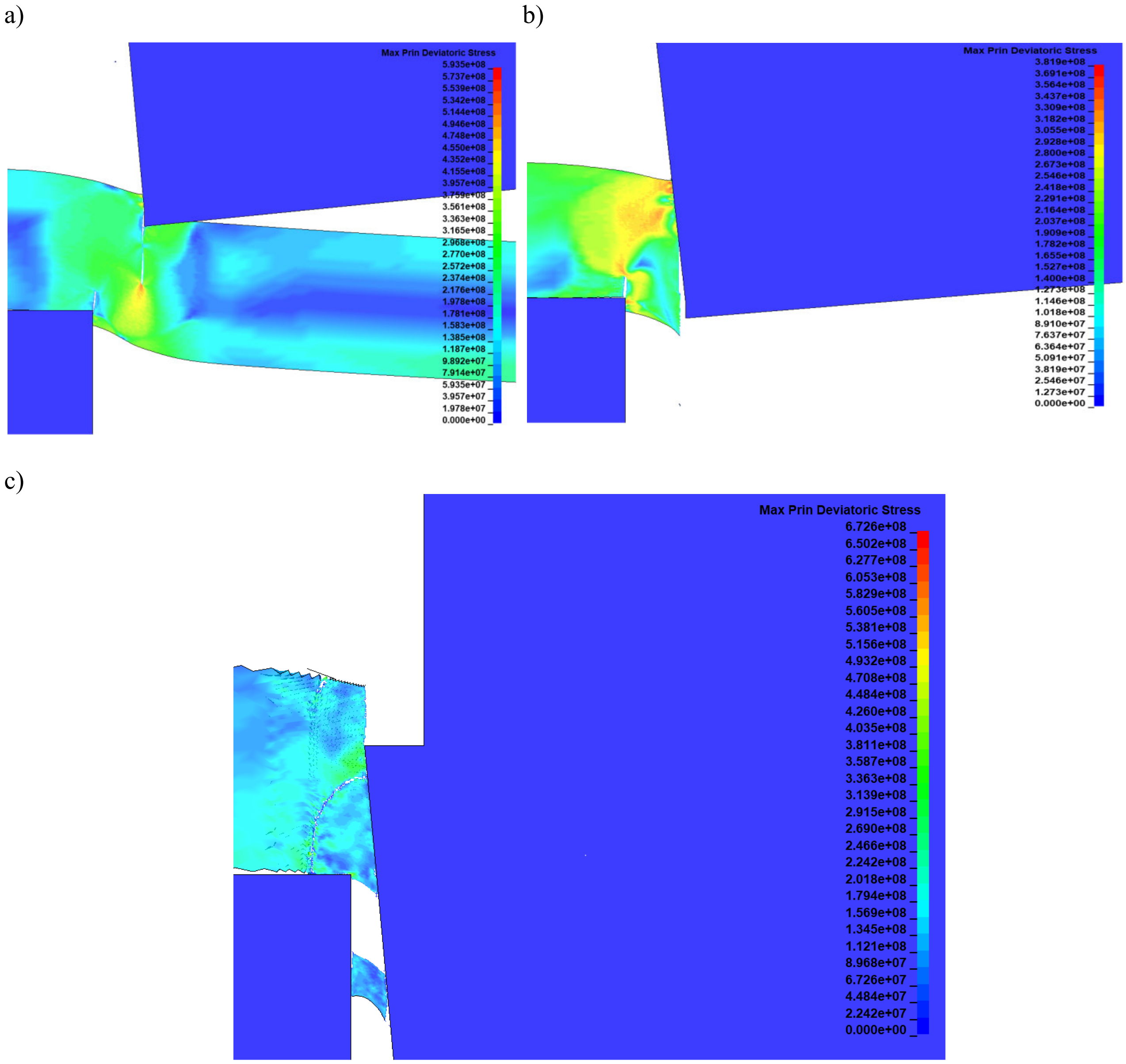

Fig. 10. Phases of cutting process: a) standard cutting, b) the beginning of the trimming process, c) end of the trimming process with visible damage to the material cut edge

Initially, the process proceeds in a standard manner, with the separation of individual phases such as elastic-plastic deformation, plastic flow, cracking, and complete separation of the material (Fig. 10a). Following this cutting process, the method involves the trimming of the edge area containing the burr (Figs. 10b and 10c). This innovative step aims to address the challenge of burr formation and improve the overall quality of the cut edge. However, during the analyses, a problem was identified related to the cracking of the material edges (Fig. 10c). This issue arises from excessive stress concentration in the cutting zone, which can lead to unintended cracks and negatively impact the integrity of the cut edge.

Therefore, a wide range of analyses were conducted to determine the appropriate values of the side edge rake angle and cutting clearance, which are critical factors influencing the maximum stresses in the cutting zone of the material post-process. The results of these investigations revealed that burr-free cutting is achievable when the clearance value is maintained at h_c = 1-3% of the sheet thickness. In this case, the rake angle of the side cutting edge allows for the obtaining of products without deviations in the perpendicularity of the cutting surface and the introduction of the appropriate state of compressive stresses in the material cutting zone. This specific clearance range minimises stress concentrations that typically lead to burr formation while ensuring efficient material separation during the cutting process (Fig. 12). In the initial stages of the process, the tool exerts a point pressure on the material. As a result, the bending moment is minimised in the plastic flow phase during the maximum hardening of the material. This causes the sheet metal to crack earlier. However, this occurs when the pure shear phase is long enough to achieve a sliding fracture on the cutting surface. Since the plastic flow phase is limited in the final phase after complete separation, a small deviation of the perpendicularity of the cutting surface is visible, which is levelled through an inclined side edge described by an angle β (Figs. 11 and 12). The proposed solution is innovative in relation to the current state of knowledge, where flat punches are used. By trimming the cutting surface, the perpendicularity of the cutting surface is obtained, and a favourable state of compressive stresses that affect, for example, the magnetic properties of electrical sheets.

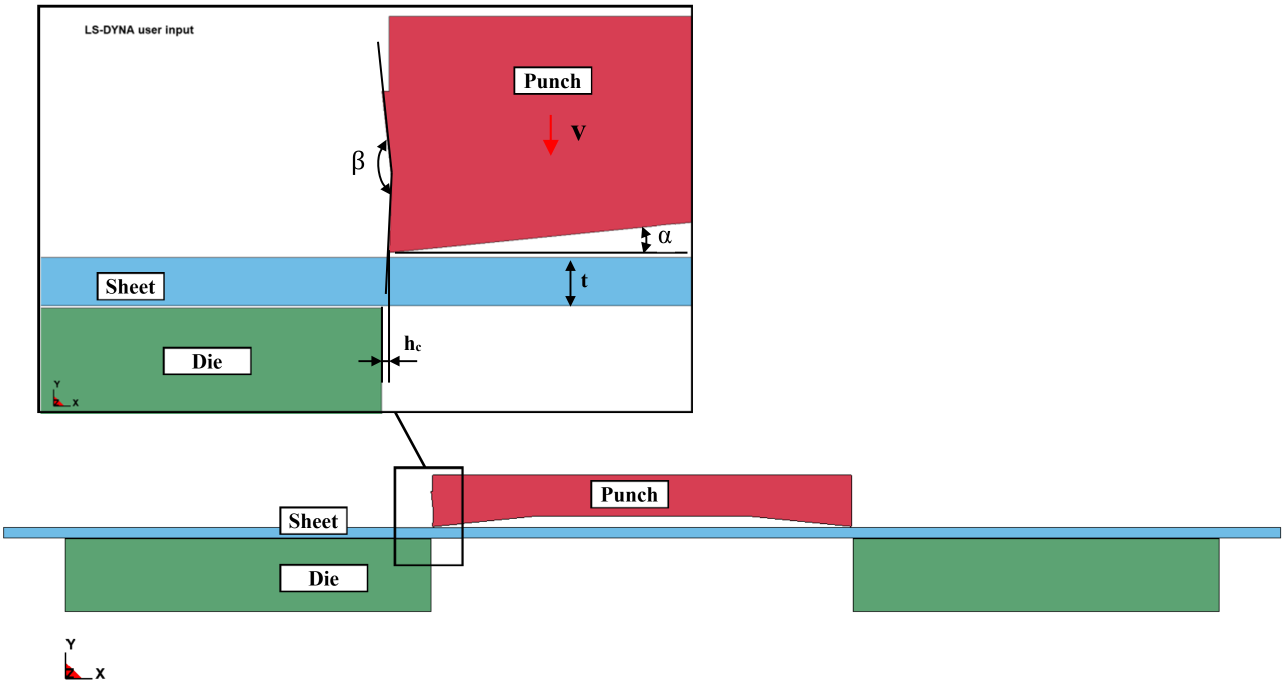

Fig. 11. Blanking process with new tool geometry: α – rake angle of cutting edge, β – rake angle of side edge, h_c – blanking clearance, t – sheet thickness, v – blanking speed

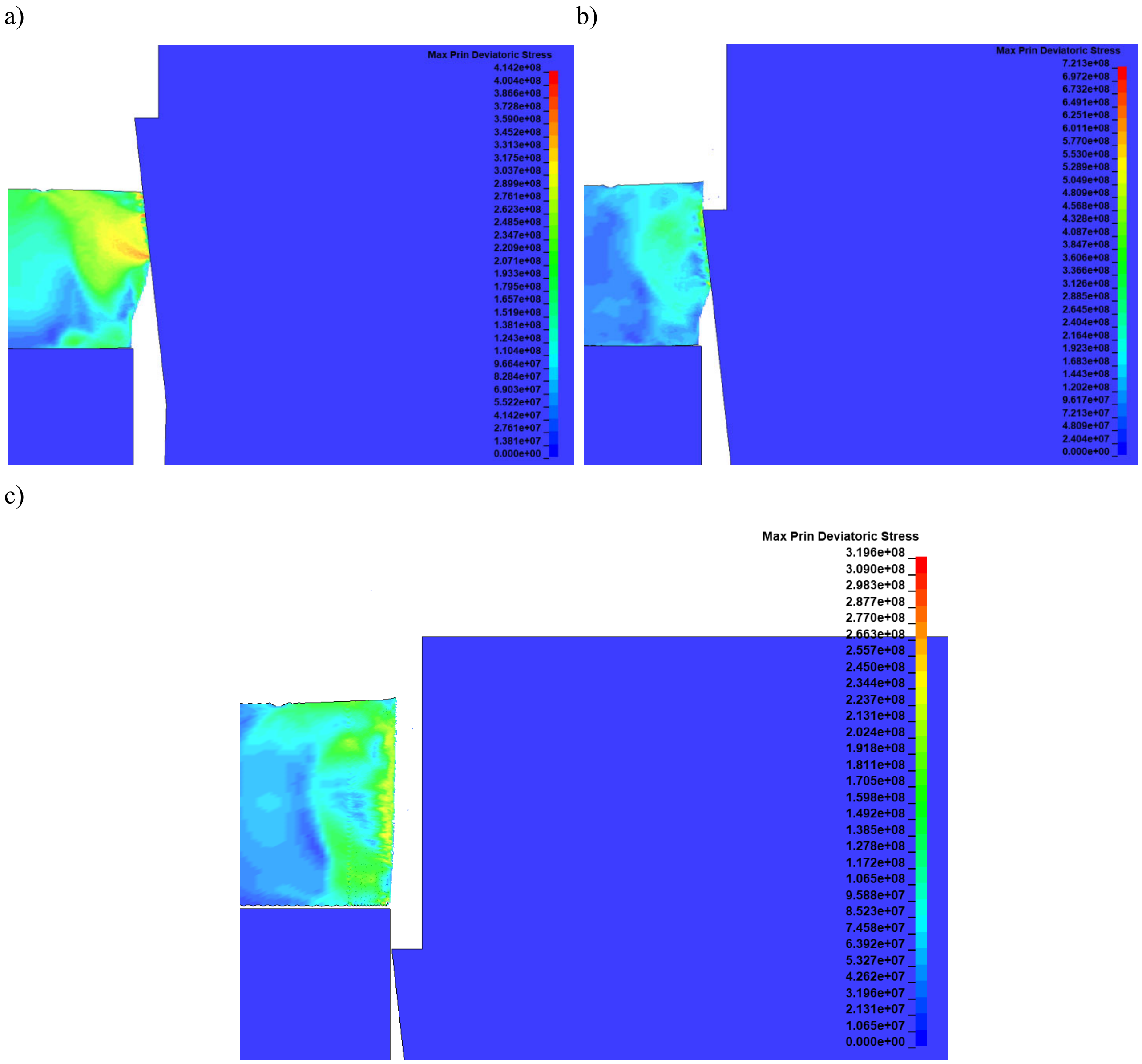

Fig. 12. Trimming with appropriate process parameter settings: a) the beginning of the trimming process, b) the middle phase, c) a view of the cut edge of material after the process

5. Conclusions

Control and prevention of burr formation in cutting processes are essential in reducing cutting waste. Burr formation depends mainly on the workpiece material ductility, cutting parameters, cutting tool geometry, and tool wear. In this paper, based on the analysis of the state of knowledge and own research, methods of reducing burrs on the cut surfaces of elements cut from metal materials were proposed. Due to the complexity of the problem, the focus was on the possibility of reducing product defects by appropriately controlling the technological parameters of the process. Simulation and experimental studies were used for this purpose. A new cutting method with the trimming process was proposed, allowing for the removal of unnecessary burrs from the cut edge of the material in one operation. For standard cutting and blanking, the cutting clearance should be approximately set h_c = 5-10% of the thickness of the cut material. The clearance value should be selected when cutting on circular shears depending on the rake angle. With the increase of the rake angle, the burr height decreases, but only in the clearance value range of h_c = 2-15% of the material thickness. When cutting with trimming, the cutting clearance value should be within h_c = 1-3% of the material thickness. This allows for a high-quality cut edge that is free from burrs.

In terms of environmental protection, burr reduction is necessary because they generate waste already at the stage of cutting out blanks from sheets, e.g. electrical sheets. Another problem is related to the process of sheet stacking in the core of transformer motors. Excessive burr prevents stacking. Grinding the cutting edges is necessary. Even in the case of successful stacking, an excessive burr can negatively affect energy losses and eddy currents, which adversely affect the efficiency of electrical devices. This phenomenon is visible in the magnetic cores of AC circuits, which are made of materials that conduct electricity, e.g., generators or transformers. For this reason, these elements are not manufactured from uniform blocks of metal but consist of, for example, stacks of thin sheets mutually insulated by a layer of insulation. The lack of burrs increases the durability of devices, e.g. transformers, and lower energy consumption (no costs of improving the product).

References

Arslan, Y. (2020). The effects of cryogenic process on the AISI M2 punch materials and on the hole edge geometry of the DIN EN 10111-98 sheet metal control arm parts. *Advances in Materials Science and Engineering*, *12*, 1-11.

Barik, J., Sonkamble, V., Narasimhan, K. (2018). Burr Formation and Shear Strain Field Evolution Studies During Sheet Metal Blanking. *IOP Conference Series: Materials Science and Engineering*, *418*, 012068. https://doi.org/10.1088/1757-899X/418/1/012068

Bohdal, Ł., Patyk, R., Tandecka, K., Gontarz, S., Jackiewicz, D. (2020). Influence of shear-slitting parameters on workpiece formation, cut edge quality and selected magnetic properties for grain-oriented silicon steel. *Journal of Manufacturing Processes*, *56*, part A, 1007-1026.

Bohdal, Ł., Kukiełka, L., Patyk, R., Kośka, K., Chodór, J., Czyżewski, K. (2022). Experimental and numerical studies of tool wear processes in the nibbling process. *Materials*, *15*(1), 107.

Cao, H., Hao, L., Yi, J., Zhang, X., Luo, Z., Chen, S., Li, R. (2016). The influence of punching process on residual stress and magnetic domain structure of non-oriented silicon steel. *Journal of Magnetism and Magnetic Materials*, *406*, 42-47.

Cavusoglu, O., Gürün, H. (2017). The relationship of burr height and blanking force with clearance in the blanking process of AA5754 aluminium alloy. *Transactions of FAMENA*, *41*(1), 55-62.

Demmel, P., Hoffmann, H., Golle, R., Intra, C., Volk, W. (2015). Interaction of heat generation and material behaviour in sheet metal blanking. *CIRP Annals – Manufacturing Technology*, *64*, 249-252.

Dems, M., Gmyrek, Z., Komeza, K. (2023). The influence of cutting technology on magnetic properties of non-oriented electrical steel-review state of the art. *Energies*, *16*, 4299.

Ghadbeigi, H., Al‑Rubaye, A., Robinson, F.C.J., Hawezy, D., Birosca, S., Atallah, K. (2020). Blanking induced damage in thin 3.2% silicon steel sheets. *Production Engineering*, *14*, 53-64.

Gréban, F., Monteil, G., Roizard, X. (2007). Influence of the structure of blanked materials upon the blanking quality of copper alloys. *Journal of Materials Processing Technology*, *186*, 27-32.

Hamzehbahmani, H., Anderson, P., Jenkins, K., Lindenmo, M. (2016). Experimental study on inter-laminar short-circuit faults at random positions in laminatedmagnetic cores. *IET Electric Power Applications*, *10*(7), 604-613.

Han, S., Chang, Y., Wang, C., Han, Y., Dong, H. (2022). Experimental and numerical investigations on the damage induced in the shearing process for QP980 steel. *Materials*, *15*, 3254.

He, J., Wang, Z., Li, S., Dong, L., Cao, X., Zhang, W. (2019). Optimum clearance determination in blanking coarse-grained non-oriented electrical steel sheets: experiment and simulation. *International Journal of Material Forming*, *12*, 575-586.

Husson, A., Correia, J.P.M., Daridon, L., Ahzi, S. (2008). Finite elements simulations of thin copper sheets blanking: Study of blanking parameters on sheared edge quality. *Journal of Materials Processing Technology*, *199*, 74-83.

Poór, D.I., Geier, N., Pereszlai, C., Xu, J. (2021). A Critical Review of the Drilling of CFRP Composites: Burr formation, Characterisation and Challenges. *Composites Part B: Engineering*, *223*, 109155, ISSN 1359-8368, https://doi.org/10.1016/j.compositesb.2021.109155

Weiss, H.A., Leuning, N., Steentjes, S., Hameyer, K., Andorfer, T., Jenner, S., Volk, W. (2017). Influence of shear-cutting parameters on the electromagnetic properties of non-oriented electrical steel sheets. *Journal of Magnetism and Magnetic Materials*, *421*, 250-259. https://doi.org/10.1016/j.jmmm.2016.08.002

Wiedenmann, R., Sartkulvanich, P., Altan, T. (2009). FEA on the effect of sheared edge quality in blanking upon hole expansion of advanced high strength steel. *IDDRG 2009*.