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Influence of coolant pressure on the wear and tool life of gun drills in deep drilling of 24CrMoV5-5 steel

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ABSTRACT

In modern material processing industries, the constant need for increased efficiency and precision drives ongoing research aimed at optimizing technological parameters. The presented study aims to analyze excessive wear and chipping of gun drills during the deep drilling process of 24CrMoV5-5 steel. The experiment was conducted on a horizontal deep drilling machine, model T30-2-500 (TBT Tiefbohrtechnik GmbH+Co), under real production conditions. The investigation included the performance analysis of both factory-reground and subsequently reground drills, with the number of tests enabling a detailed comparison across different process regimes. The process parameters were systematically varied in three phases, with a focus on increasing the coolant pressure from 50 to 60 bar, while other conditions, such as spindle speed and feed rate, remained constant. The results indicate that increasing coolant pressure allows for more efficient cooling, stabilization of temperature fluctuations in the cutting zone, and improved chip evacuation, directly leading to reduced chipping and more uniform tool wear. Consequently, this extends the service life of the drills and preserves the high precision of the machined surface. The obtained results provide valuable guidelines for optimizing deep drilling parameters, highlighting the importance of properly adjusted cooling conditions in industrial machining. Future research will focus on integrating additional processes, including variations in cutting speed, the application of different cooling techniques, and the implementation of intelligent tool condition monitoring systems, aiming to achieve an optimal balance between process efficiency and tool longevity.

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1. INTRODUCTION

The metal processing industry forms the foundation of modern manufacturing, where continuous efforts are made to enhance precision and reliability in order to meet the demands of the global market. Technological advancements and increasing competition drive the development of new methodologies and processes, directly impacting product quality and production efficiency. This development is crucial for highly demanding industrial sectors such as the aerospace, automotive, and defense industries, whose requirements often exceed the standards of conventional manufacturing. In this context, the exploration of innovative approaches in metal processing becomes imperative, justifying a detailed analysis of specific operations such as deep drilling [1,2].

Deep drilling is a crucial operation in metal processing, enabling the precise creation of deep holes required for highly demanding applications. Although the process has proven to be efficient, it faces challenges related to tool

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wear and chipping, which directly affect machining quality and tool longevity. These issues pose significant challenges in maintaining process stability and achieving high precision standards, particularly when machining difficult-to-cut materials such as titanium, Inconel 718, and manganese steel [1,2].

Tool wear is one of the key factors affecting the efficiency of deep drilling. Research has shown that wear can be significantly reduced by optimizing machining parameters such as cutting speed and coolant pressure. Baumann A. and Eberhard P. determined that increasing coolant pressure significantly reduces tool temperature, leading to lower friction between the tool and the workpiece, thereby decreasing wear and extending tool life [3]. The research conducted by Pollák M. et al. shows that reducing the feed rate contributes to improved process stability and vibration reduction, further minimizing tool wear [4]. In parallel, the analysis of the influence of drill geometry variations—particularly the shape of the cutting edges and cutting edge length—indicates that a tool design with longer cutting edges can extend drill life but simultaneously increases friction and energy consumption. Conversely, a shorter cutting edge design can reduce friction and wear, although it may potentially compromise drilling precision [5]. These findings highlight the need for carefully balancing all machining parameters, including tool geometry, cutting speed, and coolant pressure, to achieve optimal process efficiency. At the same time, questions remain regarding the effects of specific geometric parameters on drilling precision and tool wear, presenting a perspective for future research.

According to the research by Wang et al., the application of specialized coatings, such as TiAlN, can significantly reduce friction and tool wear [6]. Tool chipping is another significant issue affecting drilling precision, particularly in cases where the tool encounters materials with high hardness and toughness. According to the research by Cui et al., the use of a specialized tool design with groove-type chip breakers can reduce tool overheating and help stabilize the drilling process, thereby lowering the risk of chipping [7]. Similarly, the research by Klocke et al. demonstrates that the use of advanced simulation methods, such as 3D modeling of the deep drilling process, can aid in optimizing tool design and improving drilling precision while reducing the negative effects of chipping [8]. Additionally, research focused on vibrations and chatter effects has the potential to enhance process stability and reduce tool wear [7,9].

As part of the optimization of coolant pressure during drilling, Kočiškov M. et al. study shows that increasing pressure leads to reduced chipping and improved chip evacuation efficiency, thereby lowering the risk of tool overheating [10]. The research by Oezkaya E. et al. focuses on tool wear at the micro level, highlighting the importance of applying advanced cooling technologies in combination with specialized coatings [11]. The results of these studies suggest that the combined application of optimized coolant pressure and innovative cooling methods can significantly contribute to reducing abrasive wear and improving the precision of the deep drilling process.

During the deep drilling process, numerous defects have been identified that significantly affect tool performance. Table 1 provides an overview of the most common defects, their causes, and descriptions.

Despite the significant attention previous research has devoted to individual parameters affecting tool wear, relatively few studies have systematically examined the effectiveness of integrating multiple factors. In particular, the synergistic influence of tool geometry regrinding and optimized cooling conditions during deep drilling is rarely addressed, especially in the machining of materials such as 24CrMoV5-5 steel and similar alloys. In this context, the objective of this study is to investigate the impact of different cooling parameters, with a particular emphasis on coolant pressure, on tool life and the quality of the deep drilling process.

Table 1 - *Defects in deep drilling, their causes, and descriptions [2,3,5-7,11-13].*

Defect	Description	Cause
Abrasive Wear	Contact between the tool and the chip results in the wearing away of the tool material, which manifests as an abraded band along the cutting edge.	Presence of abrasive particles in the chip.
Adhesive Wear	Interaction between the tool and the workpiece leads to the accumulation of workpiece material on the tool.	Chemical interaction with the workpiece material.
Thermal Wear	Prolonged exposure to high temperatures alters the tool's microstructure, as evidenced by changes in the chip and cutting edge colors.	Excessive heating and inefficient cooling.
Cutting Edge Chipping	Damage to the cutting edge occurs due to high cutting forces and improper chip removal.	Excessive cutting forces and poor chip evacuation.
Material Adhesion	The formation of layers of workpiece material on the tool interferes with the normal cutting process.	Insufficient lubrication and high temperature in the cutting zone.
Micro-cracks	These develop as a result of cyclic loads and sudden changes in cutting forces.	High cyclic loading and abrupt force changes.
Tool Breakage	Complete tool failure occurs due to extreme wear, chipping, or thermal overload.	Excessive wear or impact loads during drilling.

The obtained results will contribute to a better understanding of deep drilling process optimization, enabling industries that machine difficult-to-cut materials to enhance their production processes, reduce tool maintenance costs, and increase overall efficiency.

2. MATERIALS AND METHODS

The tool testing in the deep drilling process was conducted on a horizontal deep drilling machine; model T30-2-500 (TBT Tiefbohrtechnik GmbH+Co, https://www.tbt.de/). This machine enables precise execution of the deep drilling process due to its high positioning accuracy, rigid construction, and optimized chip flushing system. The key technical specifications of the machine include:

- Maximum drilling depth: 500 mm,
- Drilling diameter: 4–30 mm,
- Main spindle speed: 550–6400 rpm,
- Feed rate: 35–320 mm/min,
- Maximum coolant pressure: 80 bar,
- Coolant system type: Internal flushing.

Figure 1 illustrates the machine in operation, showing the arrangement of the tool and the workpiece during the drilling process.

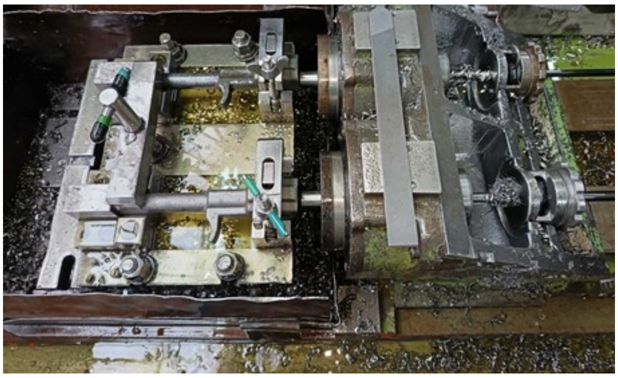
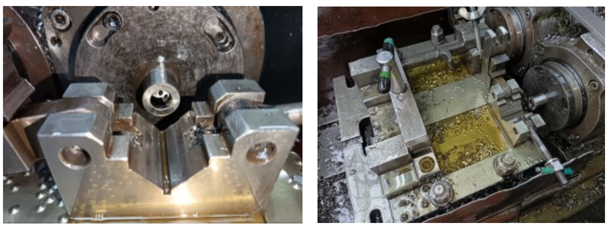


Fig. 1 *Tool testing in the deep drilling process: Machine in operation.*

The workpiece clamping and guiding system consisted of a bushing with a gun drill (Fig. 2a), which ensures precise initial tool guidance, and prisms for clamping and centering the workpiece (Fig. 2b), which secure the accurate positioning of the workpiece during machining. The tools and accessories used were configured to ensure the stability and repeatability of the deep drilling process.

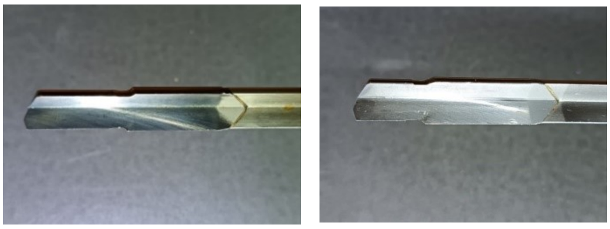


a) b)

Fig. 2 *Tools and Fixtures for Workpiece Clamping: a) Bushing with a gun drill for initial drill guidance, and b) Prisms for workpiece clamping and centering*

The sample material was 24CrMoV5-5steel. The tested samples were forgings, and their average hardness, determined using the Vickers method, ranged from 208 to 253 HV/30 (measured at +20°C).

The tests involved drilling holes with a length of 196.5 mm within the processed samples. The hole diameter was formed using a two-step gun drill with a diameter of Ø10.7/Ø12.2 mm, featuring a cutting tip made of hard carbide (H15 carbide type). Fig. 3a shows the factory-reground drill, while Fig. 3b presents the subsequently reground drill before testing (manufacturer: Botek). The drill had an internal cutting edge angle of $\alpha = 11°$, an external angle of $\beta = 24°$, and a total length of $l = 600$ mm.



a) b)

Fig. 3 *Condition of Drills Before Testing; a) Factory-Reground Drill, and b) Subsequently Reground Drill.*

As part of this study, tests were conducted on new and reground gun drills (Fig. 3) under defined deep drilling conditions in real production environments. The objective of the testing was to analyze the impact of process parameters, particularly coolant pressure, on reducing cutting edge chipping and improving tool longevity.

For the analysis of tool wear effects after drilling, a universal measuring microscope, UIM-21 (Fig. 4), was used. The microscope specifications are as follows:

- Magnification: 10–50×,
- Measurement error: 1 + L/100 µm,
- Resolution: 0.0002 mm,
- Measurement range: 200 mm.

Using this device, wear bands on the outer, inner, and lateral cutting edges of the drills were precisely measured, enabling a detailed assessment of tool longevity under different machining conditions.

Fig. 4 *Measurement of wear bands using the universal measuring microscope UIM-21.*

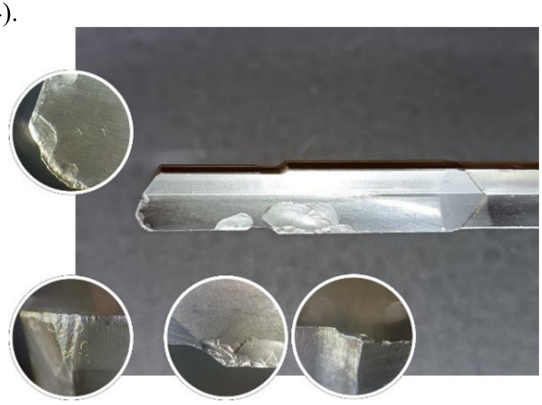
The experiment was conducted in multiple phases, with machining parameters adjusted according to the observed issues, as follows:

- **Phase I**: Coolant pressure 5.0 MPa (50 bar), spindle speed n = 1200 rpm, feed rate f_1 = 60 mm/min (for the first 50 mm) and f_2 = 70 mm/min (for depths greater than 50 mm);
- **Phase II**: Coolant pressure 5.5 MPa (55 bar), aimed at improving chip evacuation and reducing the occurrence of microdamage on the cutting edges; spindle speed n = 1200 rpm, feed rate f_1 = 60 mm/min (for the first 50 mm) and f_2 = 70 mm/min (for depths greater than 50 mm); and
- **Phase III**: Coolant pressure 6.0 MPa (60 bar), aimed at optimizing lubrication and reducing cutting edge chipping; spindle speed n = 1200 rpm, feed rate f_1 = 60 mm/min (for the first 50 mm) and f_2 = 70 mm/min (for depths greater than 50 mm).

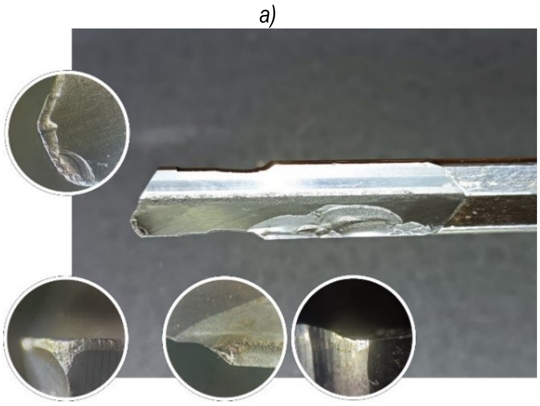
Based on these tests, changes in tool life and the quality of the machined surface were monitored, with the results being thoroughly analyzed through visual inspection and microscopic measurements of tool wear.

3. RESULTS

The results present the effects of different deep drilling regimes on tool longevity, machined surface quality, and the occurrence of defects on the cutting edge. The tests included both factory-reground and subsequently reground drills, analyzing the impact of varying coolant pressure on chip evacuation efficiency and tool wear (Figs. 5–7, Tables 2–4).



a)



b)

Fig. 5 *Coolant Pressure at 50 bar for Chip Flushing: a) Damage to the new (factory-reground) drill, and b) Damage to the reground drill.*

During the initial testing, it was observed that the deep drilling process, as defined by the company Zastava Arms (www.zastava-arms.rs), exhibited issues related to cutting edge chipping and chip accumulation in the cutting zone. The tests were conducted at a spindle speed of 1200 rpm, with a feed rate of 60 mm/min for the first 50 mm of the hole, increasing to 70 mm/min beyond 50 mm depth, while the coolant pressure was set at 5.0 MPa (50 bar). Under these conditions, the service life of the factory-reground drill was 11.7 meters, whereas the subsequently reground drill lasted 10.6 meters.

Analysis of the drilled holes and visual inspection of the tools (Fig. 5) revealed that inadequate chip evacuation leads to increased friction and localized overheating, resulting in microdamage on the cutting edge. The damage was particularly pronounced in reground drills, indicating that the current machining regimes were not optimized for achieving a stable drilling process.

The measured wear bands for the new and reground drills are presented in Table 2.

Table 2 - *Measured wear bands for the new and reground drill (50 bar).*

Drill Status	New Drill	Reground Drill
Primary rake face	1,21 mm	1,132 mm
Secondary rake face	1,13 mm	1,423 mm
Primary flank face	0,543mm	0,371mm
Secondary flank face	0,224mm	0,218mm

To improve chip evacuation and reduce tool damage, the coolant pressure was increased to 5.5 MPa (55 bar), while other process parameters remained unchanged. The results showed a reduction in cutting edge chipping and an increase in tool longevity. Under these conditions, the factory-reground drill achieved a service life of 42.3 meters, while the subsequently reground drill lasted 38.4 meters. Additionally, an improvement in the machined surface quality was observed, indicating a more stable cutting process and reduced thermal loads (Fig. 6). Fig. 6a shows that increasing coolant pressure to 55 bar for better cooling, lubrication, and chip removal led to damage on the new (factory-reground) drill, possibly contributing to tool failure.

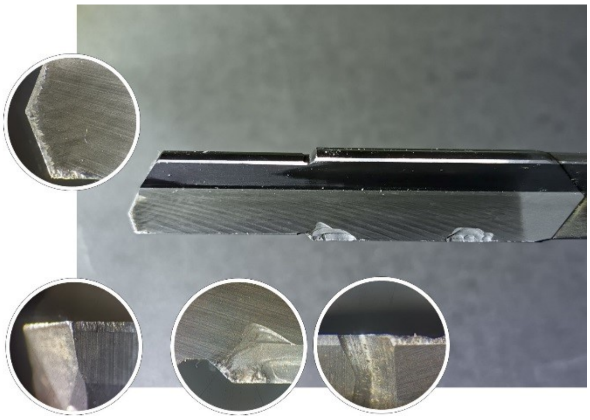


Fig. 6a *Coolant Pressure Increased by 5 Bar to 55 Bar for Cooling, Lubrication, and Chip Flushing: Damage to the new (factory-reground) drill.*

As shown in Fig. 6b, increasing the coolant pressure to 55 bar resulted in visible damage to the reground drill, despite the intended improvements in cooling, lubrication, and chip evacuation.

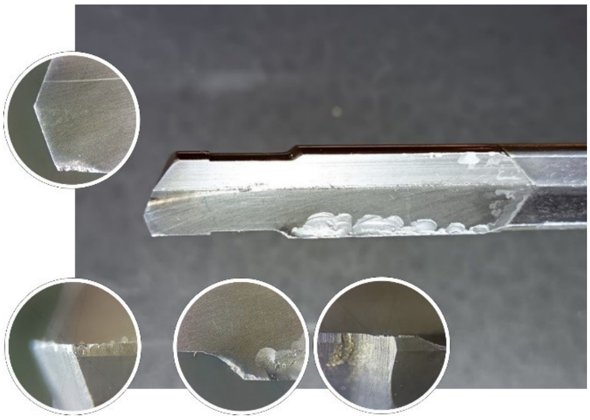


Fig. 6b *Coolant Pressure Increased by 5 Bar to 55 Bar for Cooling, Lubrication, and Chip Flushing: Damage to the reground drill.*

The measured wear bands for the new and reground drills at 55 bar coolant pressure are presented in Table 3. The values reflect the effect of elevated pressure on tool wear under identical machining conditions

Table 3 - *Measured wear bands for the new and reground drill (55 bar).*

Drill Status	New Drill	Reground Drill
Primary rake face	0,335mm	0,305mm
Secondary rake face	0,223mm	0,112mm
Primary flank face	0,270mm	0,303mm
Secondary flank face	0,135mm	0,107mm

At 60 bar, additional benefits were achieved in terms of tool longevity and process stability. In this operating regime, cutting edge chipping was completely eliminated, ensuring optimal tool stability during the drilling process. Additionally, tool wear became more uniform, indicating better control of cutting forces in the cutting zone and optimal lubrication conditions (Fig. 7). As shown in Fig. 7a, increasing the coolant pressure by 5 bar to a total of 60 bar for cooling, lubrication, and chip flushing resulted in damage to the new (factory-reground) drill.

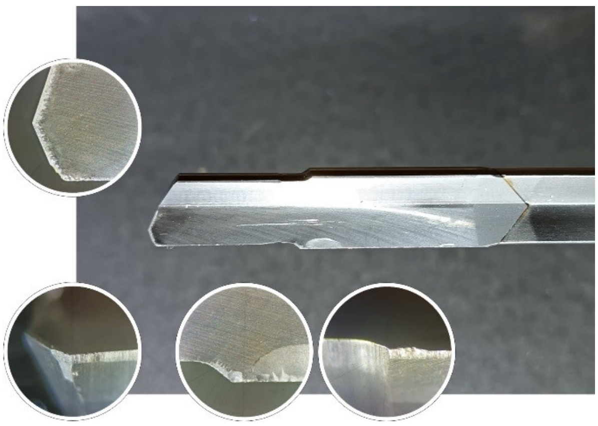
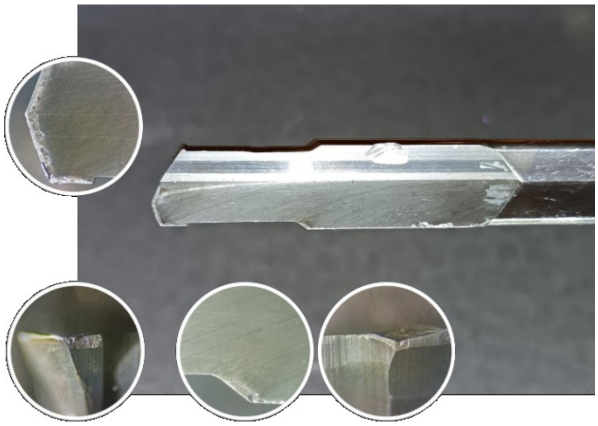


Fig. 7a *Coolant Pressure Increased by 5 Bar to 60 Bar for Cooling, Lubrication, and Chip Flushing: Damage to the new (factory-reground) drill.*

As presented in Fig. 7b, after increasing the coolant pressure to 60 bar, visible damage was also observed on the reground drill. Despite the intention to improve cooling, lubrication, and chip evacuation, the elevated pressure appears to have contributed to wear or failure of the tool.



b)

Fig. 7b *Coolant Pressure Increased by 5 Bar to 60 Bar for Cooling, Lubrication, and Chip Flushing: Damage to the reground drill.*

Increasing the coolant pressure significantly extended the tool life, with the factory-reground drill lasting 86.4 meters, while the subsequently reground drill lasted 80.7 meters. The measured wear bands for the new and reground drills are presented in Table 4.

Table 4 - *Measured wear bands for the new and reground drill (60 bar).*

Drill Status	New Drill	Reground Drill
Primary rake face	0,274mm	0,461mm
Secondary rake face	0,270mm	0,353mm
Primary flank face	0,460mm	0,384mm
Secondary flank face	0,285mm	0,326mm

4. DISCUSSION

This study conducted a detailed analysis of defects occurring on gun drills during the deep drilling process, with a particular focus on wear, chipping, and material buildup. Experimental results indicate that cooling efficiency, proper chip evacuation, and strict control of machining parameters are key factors that significantly influence tool longevity and machining quality.

According to the results of this study, increasing coolant pressure significantly reduces cutting edge chipping, directly contributing to the extension of tool life. Experimental analysis shows that applying a pressure of 60 bar enables more efficient chip evacuation, prevents chip accumulation, and reduces friction in the cutting zone. This establishes optimal conditions for a stable drilling process, leading to an extended tool lifespan while maintaining machining precision and surface quality [1-3].

In studies addressing similar topics, such as the work of Kočiško et al., the authors demonstrated that increasing coolant pressure has a direct impact on reducing tool wear

[10]. In this study, an increase in coolant pressure by 5 bar resulted in reduced chipping and increased tool longevity. These results align with our findings, where an additional 5-bar pressure increase, bringing the total to 60 bar, led to the complete elimination of chipping and uniform wear on the rake face. A similar study by K.S. Woon et al. confirms that improved cooling and chip evacuation can mitigate negative effects such as overheating and wear, which is consistent with our results regarding the effectiveness of increased coolant pressure in comparison to previous research [14].

Although our results align with studies focused on optimizing cooling parameters, differences in the applied methodologies can be observed in the approach to varying cutting speed and feed rate. For example, in the study by Astakhov V.P. and Galitsky V.V., the authors experimented with different tool geometries and cutting speeds, concluding that the proper combination of these parameters significantly extends tool life and reduces wear [9]. However, our study focused exclusively on varying coolant pressure, whereas the mentioned research optimized all process parameters simultaneously, providing additional context for our analysis.

Additionally, the study by Sihvo I. and Varis J. highlights the importance of applying advanced real-time tool condition monitoring methods, such as cutting force analysis, which could be beneficial for further optimizations in our research [15,16]. Based on the analysis of these signals, the authors developed predictive wear models that can be used in industrial settings for precise tool condition tracking. Although this method was not applied in our study, the implementation of similar technologies could contribute to even more precise analysis in future research.

While this study successfully achieved improvements in reducing chipping and increasing tool longevity, the results indicate that further optimization is still possible. Increasing coolant pressure has proven effective in minimizing chipping, but future research should focus on balancing all process parameters, including cutting speed and feed rate. Additionally, K.S. Woon et al. emphasize the importance of tool geometry precision, which may be relevant for further research in the context of optimizing the geometric characteristics of gun drills [16]. Our research could be expanded by analyzing different cutting edge geometries and testing their impact on wear, in combination with variations in process parameters.

5. CONCLUSION

Based on the conducted research, it was established that increasing coolant pressure from 50 to 60 bar significantly reduces tool wear and extends tool life in the deep drilling process of 24CrMoV5-5 steel. The increased pressure enables more efficient cooling, stabilization of temperature fluctuations in the cutting zone, and reduction of chipping, thereby maintaining high precision machining standards. These results confirm the importance of optimizing cooling parameters as a key factor in improving the deep drilling process and provide relevant guidelines for industrial applications in the machining of difficult-to-cut materials. Future research will focus on integrating additional process parameters, including variations in cutting speed and the application of different cooling techniques, as well as the implementation of intelligent methods, such as advanced tool condition monitoring systems and wear prediction algorithms. Such a multidisciplinary approach would enable the achievement of an optimal balance between process efficiency and tool longevity, further enhancing competitiveness and productivity in industrial metal machining.

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REFERENCES

[1] Ahmed, A., Lew, M.T., Diwakar, P., Kumar, A.S., Rahman, M. (2019). A novel approach in high performance deep hole drilling of Inconel 718. *Precision Engineering, 56*, 432–437, DOI: 10.1016/j.precisioneng.2019.01.012.

[2] Arunkumar, N., Thanikasalam, A., Sankaranarayanan, V., Senthilkumar, E. (2018). Parametric optimization of deep-hole drilling on AISI 1045 steel and online tool condition monitoring using an accelerometer, *Materials and Manufacturing Process*, 33(16), 1751–1764, DOI: 10.1080/10426914.2018.1476757.

[3] Baumann, A., Eberhard, P. (2023). Investigation of Chip Jamming in Deep-Hole Drilling. 2023 International SPHERIC Workshop.

[4] Pollák, M., Kočiško, M., Petrus, J., Grozav, S.D., Ceclan, V. (2022). Research into the Impact of Spindle Speed and Feed Rate Changes on the Life of a Deep-Drilling Technology Tool, *Machines*, 10(4), DOI: 10.3390/machines10040268.

[5] Xie, C., Li, L., Zhang, Y., Lou, J., Pan, Y. (2022). Analysis of machining quality of 304 stainless steel deep hole by changing angle of gun drill, *International Journal of Advanced Manufacturing Technology*, 123(1–2), 287–298, DOI: 10.1007/s00170-022-10199-y.

[6] Wang, Y.G., Yan, X.P., Tu, G.C. (2012). Study on tool wear and cutting torque of gun drill, *Key Engineering Materials*, 499, 318–323, DOI: 10.4028/www.scientific.net/KEM.499.318.

[7] Cui, X., Li, Z., Pei, Q., Liu, H., Wei, Z., Yu, J. (2019). Effect of Groove-type Chip Breakers in Deep Hole Drilling of 42CrMo, IOP Conference Series: Materials Science and Engineering, 688(3), 033042, DOI: 10.1088/1757-899X/688/3/033042.

[8] Klocke, F., Abouridouane, M., Gerschwiler, K., Lung, D. (2011). 3D modelling and simulation of gun drilling, *Advanced Materials Research*, 223, 12–19,DOI: 10.4028/www.scientific.net/AMR.223.12.

[9] Astakhov, V.P., Galitsky, V.V. (2005). Tool life testing in gundrilling: An application of the group method of data handling (GMDH), *International Journal of Machine Tools and Manufacture*, 45, 509–517, DOI: 10.1016/j.ijmachtools.2004.09.003.

[10] Kočiško, M., Pollák, M., Grozav, S.D., Ceclan, V. (2023). Influence of Coolant Properties and Chip Former Geometry on Tool Life in Deep Drilling, *Applied Sciences*, 13(14), 8360, DOI: 10.3390/app13148360.

[11] Oezkaya, E., Michel, S., Biermann, D. (2021). Chip formation simulation and analysis of the mechanical loads during micro single-lip deep hole drilling of Inconel 718 with varying cooling lubricant pressure, *Production Engineering*, 15(3–4), 299–309. DOI: 10.1007/s11740-021-01021-x.

[12] Liang, J., Jiao, L., Yan, P., Cheng, M., Qiu, T., Wang, X. (2022). Research on Deep-Hole Drilling of High-Strength Steel Using Slender Gun Drill, *International Journal of Precision Engineering and Manufacturing*, 23(8), 853–868, DOI: 10.1007/s12541-022-00676-5.

[13] Messaoud, A., Weihs, C. (2009). Monitoring a deep hole drilling process by nonlinear time series modeling, *Journal of Sound and Vibration*, 321(3–5), 620–630, DOI: 10.1016/j.jsv.2008.10.028.

[14] Zhang, W., He, F., Xiong, D. (2004). Gundrill life improvement for deep-hole drilling on manganese steel, *International Journal of Machine Tools and Manufacture*, 44(2–3), 327–331, DOI: 10.1016/j.ijmachtools.2003.09.004.

[15] Woon, K.S., Kanno, S., Liu, K. (2013). The influence of drill geometric accuracy on steady tool wear development and catastrophic tool failure in high aspect ratio gundrilling of Inconel-718, *International Journal of Abrasive Technology*, 6(1), 1–15. DOI: 10.1504/IJAT.2013.053164.

[16] Woon, K.S., Chaudhari, A., Kumar, A.S., Rahman, M. (2014). The effects of tool degradation on hole straightness in deep hole gundrilling of inconel-718, Int. Sci. Comm. 6th CIRP Int. Conf. High Perform. Cut., 14, pp. 593–598. DOI: 10.1016/j.procir.2014.03.016.

[17] Sihvo, I., Varis, J. (2010). Estimation of tool wear of a gun drill using the signal curve pattern of feed force, *Mechanika*, 81(1), 71–78.