COMPREHENSIVE OPTIMIZATION OF STRUCTURAL AND TECHNOLOGICAL FACTORS FOR REDUCING CUTTING TOOL WEAR BASED ON EXPERIMENTAL STUDIES AND MATHEMATICAL MODELING

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Abstract. This paper presents a comprehensive approach aimed at reducing cutting tool wear in metal machining processes. The study considers both structural factors (tool material and coating) and technological parameters (cutting speed, feed rate, and depth of cut) in an integrated manner. Experimental investigations were conducted based on the theory of designed experiments, and the obtained data were used to develop a mathematical model describing cutting tool wear. Based on this model, a conceptual approach to optimizing cutting process parameters according to the criterion of minimizing tool wear was proposed. The obtained results can be applied for the scientific analysis of cutting processes and for the selection of optimal technological regimes under industrial conditions.

Keywords: cutting tool wear; machining process; experiment; mathematical model; optimization.

Аннотация. В данной статье представлен комплексный подход, направленный на снижение износа режущего инструмента в процессах механической обработки металлов. В исследовании в интегрированном виде рассматриваются как структурные факторы (материал и покрытие инструмента), так и технологические параметры (скорость резания, подача и глубина резания). Экспериментальные исследования были проведены на основе теории планирования эксперимента, а полученные данные использованы для построения математической модели, описывающей износ режущего инструмента. На основе разработанной модели предложен концептуальный подход к оптимизации параметров процесса резания по критерию минимизации износа инструмента. Полученные результаты могут быть использованы для научного анализа процессов резания и выбора оптимальных технологических режимов в производственных условиях.

Ключевые слова: износ режущего инструмента; процесс резания; эксперимент; математическая модель; оптимизация.

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Annotatsiya. Mazkur maqolada metallarga mexanik ishlov berish jarayonlarida kesuvchi asbob yeyilishini kamaytirishga qaratilgan kompleks yondashuv taqdim etiladi. Tadqiqotda strukturaviy omillar (asbob materiali va qoplamasi) hamda texnologik parametrlar (kesish tezligi, uzatma va kesish chuqurligi) integratsiyalashgan holda ko‘rib chiqildi. Eksperimental tadqiqotlar rejalashtirilgan eksperiment nazariyasi asosida olib borildi va olingan ma’lumotlar kesuvchi asbob yeyilishini tavsiflovchi matematik modelni ishlab chiqishda qo‘llanildi. Ushbu model asosida kesish jarayoni parametrlarini asbob yeyilishini minimallashtirish mezoni bo‘yicha optimallashtirishga konseptual yondashuv taklif etildi. Olingan natijalar kesish jarayonlarini ilmiy asosda tahlil qilish hamda ishlab chiqarish sharoitlarida optimal texnologik rejimlarni tanlashda qo‘llanishi mumkin.

Kalit so‘zlar: kesuvchi asbob yeyilishi; kesish jarayoni; eksperiment; matematik model; optimallashtirish.

INTRODUCTION

In mechanical engineering, cutting tool wear during metal machining processes has a direct impact on production efficiency. As tool wear increases, cutting forces rise, the quality of the machined surface deteriorates, and the need for frequent tool replacement emerges. Therefore, reducing cutting tool wear is a scientifically and practically significant challenge. Modern studies emphasize the large number of factors influencing cutting tool wear. However, effective results can be achieved not by considering these factors separately, but by optimizing structural and technological parameters in an integrated manner. This paper is based on such an approach.[1]

MATERIALS AND METHODS

The following objects were selected for the study:

- the turning machining process;
- cemented carbide cutting tools (uncoated and coated);
- workpieces made of structural steel.

Experimental Design

The experimental study was organized based on the theory of designed experiments. In order to identify the factors having the greatest influence on cutting tool wear and to evaluate their interactions, the following parameters were selected as the main variable factors:[2]

cutting speed (V), which determines the level of heat generation and thermal loading in the cutting zone;

feed rate (S), which affects the mechanical load acting on the cutting tool and the cutting forces;

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depth of cut (t), which is a factor determining the stability of the cutting process and the strength of the tool edge;

tool coating, selected as a structural factor, and its influence on friction conditions and the wear resistance of the cutting tool was evaluated.

These factors were adopted as the main technological and structural parameters characterizing cutting tool wear in the machining process and were used as the basis for mathematical modeling and optimization of the experimental results in subsequent stages.[3]

RESULTS

Processing of Experimental Data

where:

- **V** — cutting speed;
- **S** — feed rate;
- **t** — depth of cut.

The model coefficients were determined using statistical methods, and their reliability was evaluated by means of analysis of variance (ANOVA). The experimental data obtained were processed using mathematical and statistical methods. In order to describe cutting tool wear, a second-order regression model was developed based on the experimental data. This model enables a comprehensive evaluation of the influence of the main technological factors of the cutting process—namely cutting speed, feed rate, and depth of cut—on tool wear.

To characterize cutting tool wear, a second-order multivariate regression model was adopted based on the experimental results. The model can be expressed in the following general form:[4]

$$VB = b_0 + b_1V + b_2S + b_3t + b_{12}VS + b_{13}Vt + b_{23}St + b_{11}V^2 + b_{22}S^2 + b_{33}t^2 \quad (2)$$

where:

VB — flank wear of the cutting tool;

V — cutting speed;

S — feed rate;

t — depth of cut;

b_0 — intercept term;

b_1, b_2, b_3 — linear effect coefficients

b_{12}, b_{13}, b_{23} — interaction coefficients representing the combined effects of the factors;

b_{11}, b_{22}, b_{33} — coefficients of the quadratic terms.

This regression model describes the nonlinear nature of cutting tool wear by taking into account the main technological factors of the cutting process and their interactions. The inclusion of quadratic and interaction terms in the model enables

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a mathematical representation of the complex physical and mechanical phenomena occurring during the cutting process. The model coefficients were determined based on experimental results, and their significance was evaluated using statistical criteria. The developed model serves as a basis for optimizing cutting process parameters and for addressing the problem of reducing cutting tool wear in subsequent stages. Using the regression model, the relationships among the main technological factors of the cutting process were identified, and their effects on cutting tool wear were analyzed based on the model structure. [1,5]The selection of a second-order model made it possible to account for the nonlinear behavior of the cutting process as well as the interactions among technological parameters. The variation of tool wear with respect to cutting time is shown in Figure 1.

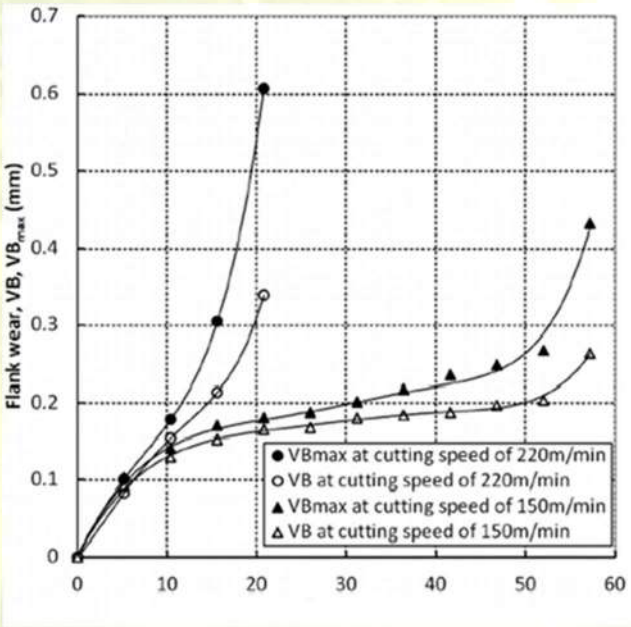


Figure 1. Dependence of cutting tool flank wear (VB) on the volume of material removed at different cutting speeds

This figure illustrates the variation of cutting tool flank wear (VB) with respect to the volume of material removed. The initial, steady-state, and accelerated wear stages are clearly observed. This behavior makes it possible to evaluate tool life and the effective operating period of the cutting tool during the machining process.

Influence of the Structural Factor

Within the scope of the experimental study, the influence of cutting tool coating on the wear process was analyzed separately as a structural factor. Coated and uncoated cutting tools were compared under identical technological conditions, which made it possible to evaluate the role of the coating in the cutting process.

The analysis showed that the tool coating, selected as a structural factor, has a significant effect on cutting tool wear in combination with technological

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parameters. In the presence of a coating, a more stable cutting process was observed, and the wear intensity was manifested in interaction with the technological factors. This approach demonstrates the necessity of analyzing structural and technological factors in a comprehensive manner and provides a scientific basis for optimizing cutting tool wear reduction. Figure 2 schematically illustrates the main types of cutting tool wear, including flank wear and crater wear, along with their characteristic geometric parameters.

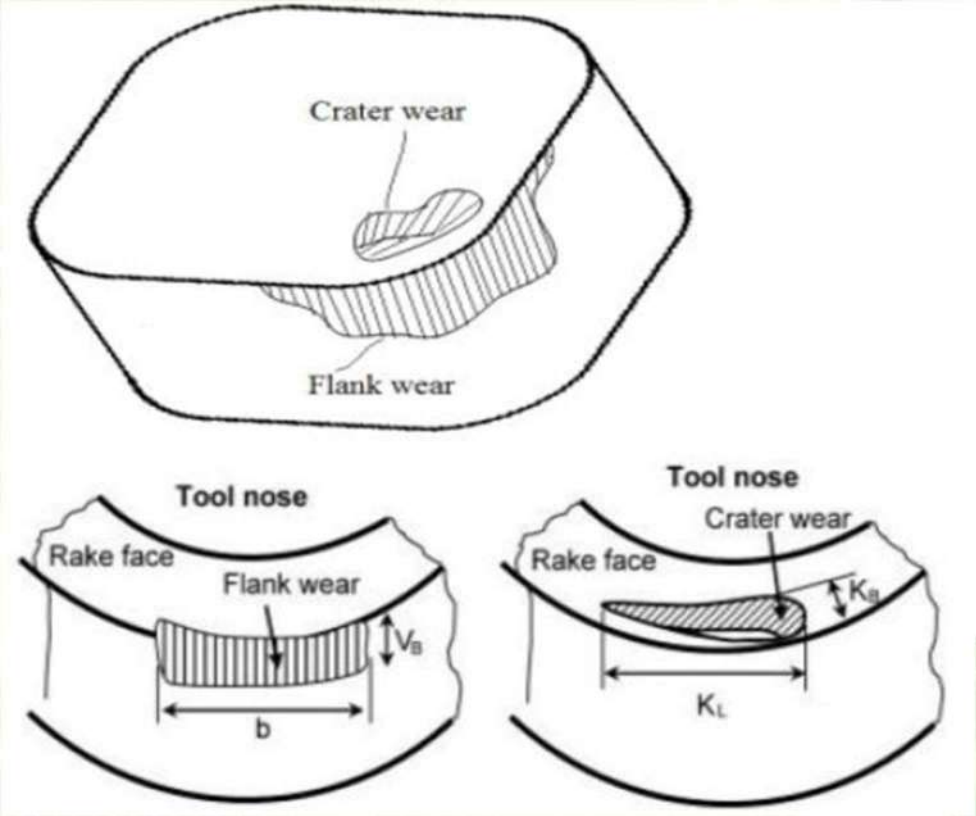


Figure 2. Influence of feed rate on cutting tool wear

This figure schematically illustrates the main types of cutting tool wear, including flank wear and crater wear, along with their characteristic geometric parameters. The diagram highlights the formation of wear on the rake face and flank surface of the cutting tool, providing a basis for understanding the wear mechanisms.

DISCUSSION

Based on the obtained results, it was found that reducing cutting tool wear cannot be achieved solely by decreasing the cutting speed. Cutting speed, feed rate, and depth of cut are interrelated, and an optimal combination of these parameters exists.[5]

Using the developed mathematical model, the optimal values of these parameters can be determined. This makes it possible to minimize tool wear while maintaining production efficiency. The application of coated cutting tools as a

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structural factor further enhances the effectiveness of the optimization process. The problem of reducing cutting tool wear in the machining process was considered as an optimization problem. The main objective of this problem is to select the structural and technological parameters of the cutting process in such a way that cutting tool wear is minimized while maintaining the stability of the technological process.

The objective function of the optimization problem is expressed as follows:

$$VB \rightarrow \min$$

Here, **VB** represents the flank wear of the cutting tool and was adopted as the primary criterion for evaluating the efficiency of the cutting process.

During the optimization process, the following constraints were taken into account:

technological stability, meaning that vibrations, unstable cutting, and damage to the tool edge must be avoided during the cutting process;

surface quality of the machined workpiece, requiring compliance with the specified surface roughness and geometric accuracy requirements;

machine tool and technological system limitations, meaning that the values of cutting speed, feed rate, and depth of cut must not exceed the power and structural constraints of the available machine tool.

Based on the mathematical model developed within these constraints, the optimal technological parameters of the cutting process were determined. This approach makes it possible to reduce cutting tool wear while maintaining production efficiency and provides a scientific basis for the comprehensive optimization of structural and technological factors.

CONCLUSION

Based on the conducted research, the following conclusions were drawn:

1. It was established that reducing cutting tool wear requires a comprehensive consideration of structural and technological factors in their interrelation.
2. An approach based on designed experiments and mathematical modeling provides an effective means for solving optimization problems related to the cutting process.
3. The use of coated cutting tools and the optimal selection of cutting regimes significantly increase tool life.

The results of this study are recommended for the scientific optimization of machining processes in mechanical engineering and for improving production efficiency.

The scientific novelty of this work lies in the comprehensive analysis of structural and technological factors affecting cutting tool wear during the cutting

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process, based on experimental investigations and mathematical modeling. Based on the results of the designed experiments, a mathematical model describing cutting tool wear was developed, and a conceptual approach to optimizing cutting process parameters was proposed. The proposed approach makes it possible to effectively reduce cutting tool wear while maintaining the stability of the technological process.

REFERENCES

1. O.Kh. Ataullaev, A.O. Ataullaev, B.T. Bisenova, Seybold Report Journal (TSRJ) 17(12), 451-461 (2022)
2. R.O. Muminov, G.E. Rayhanova, D.A. Kuziev, Experimental research and analysis of a quarry drilling rig/ Ugol' 5, 32-36 (2021).
3. D.A. Kuziev, V.V. Zotov, E.S. Sazankovaa, R.O. Muminov, Eurasian Mining 37(1), 76-80 (2022).
4. A.A. Irgashev, F.A. Ergashev, *Screw conveyor with anti-friction polymer coating for cotton transportation,* Annual International Scientific Conference on Agricultural Engineering and Green Infrastructure Solutions (AEGIS-2021) 20-21 May, Tashkent, Uzbekistan (2021)
5. Pervachev S.V., Chilikin V. M. Digital systems of radio automatic equipment. M.: Publishing house of MEI, 1999, 46 p.

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