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ТЕХНИКАЛЫҚ ҒЫЛЫМДАР ЖӘНЕ ТЕХНОЛОГИЯЛАР СЕРИЯСЫ / TECHNICAL SCIENCES AND TECHNOLOGY SERIES/ СЕРИЯ ТЕХНИЧЕСКИЕ НАУКИ И ТЕХНОЛОГИИ

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Modelling the stress-strain state of tool during the milling of hard-to-machine materials

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Abstract. This study examines the sequence of studying the stress-strain state of end mills during the machining of heat-resistant, high-alloy steel 15Kh12VMF. The study involves several stages: the creation a 3D model of the end mill, the assignment material properties, the partitioning of the geometry into finite elements, the setting of boundary conditions, and the analysis of the solution results. The components of the cutting forces are applied to the immediate contact area of the helical cutting edge with the workpiece, while the torque is applied about the cutter axis. Both the cutting force components and the torque are calculated for critical cutting conditions. The results of the strength calculations can be utilised in end mill design optimisation.

Keywords: high speed milling, end mill, finite element, stress, deformation, heat-resistant steel.

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Introduction

In engineering enterprises across the Republic of Kazakhstan, parts of process equipment and machinery are often exposed to challenging production environments. As a result, they are manufactured from special alloys, including titanium alloys, as well as high-alloy, corrosion-resistant, and heat-resistant steels, all of which are difficult-to-machine materials [1,2]. One such material, widely utilised in engineering production, particularly by Gidro Stanko Servis LLC, is the heat-resistant high-alloy steel 15Kh12VMF. This steel belongs to the martensitic-ferritic class and exhibits a Brinell hardness ranging from HB 229 to 269. It is employed in the manufacture of components that operate under high-temperature conditions, such as gas distributor housings, rotary kiln bandages for cement production, turbine parts, and more.

During the machining of the aforementioned parts, a significant portion of the mechanical operations involves milling pockets, grooves, and ledges, typically performed with end mills. These operations generally require high cutting parameters for the efficient processing of such materials. However, under these conditions, the consumption of end mills is considerable [3]. This is particularly noticeable during high-speed milling of complex shapes on advanced CNC machines. In the high-speed milling of heat-resistant, high-alloy steel 15Kh12VMF, it has been observed that at spindle speeds exceeding nшп ≥6000–7000 rpm, noticeable wear occurs on the cutting edges of the tools [4,5]. Consequently, the study of the stress-strain state (SSS) of tools during the milling of hard-to-machine materials is highly relevant. Specifically, in the design of milling processes for such materials, it is crucial to account for limitations imposed by cutting conditions. Addressing these challenges necessitates the development of methods for investigating the stress-strain state of end mills.

To address this problem, the multifunctional software Ansys Workbench (WB) will be utilised. This research was conducted as part of the grant-funded project AP19175058, titled "Numerical Modelling of Cutting Processes for Difficult-to-Machine Materials in the Context of Machine-Building Enterprises of the Republic of Kazakhstan," aimed at supporting young scientists.

Modelling of the Stress-Strain State of an End Mill and Analysis of the Results

Creation of a 3D Model of the 'Tool-Workpiece' System

The geometry of the three-dimensional model of the end mill is shown in Figure 1.

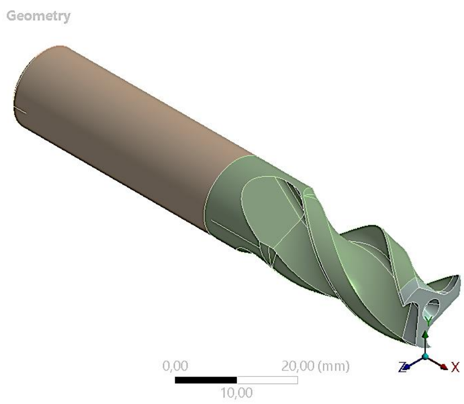


Figure 1. 3D geometry of the end mill

Purpose of the material

To carry out a strength calculation of a carbide end mill, the following parameters are sufficient as characteristics: $E=2\cdot10^{11}$ Pa – Young's modulus, $\nu=0.3$ – Poisson's ratio and $\rho=7850$ kg/m^3 – density [6,7].

Creation of a finite element model

The most critical areas of the end mill were broken down into smaller end elements (Figure 2).

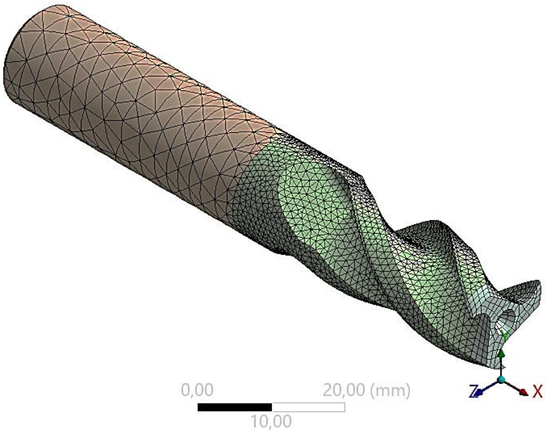


Figure 2. Finite element mesh

Setting boundary conditions

At this point, the cutting force (A) 339.3N was formed from the component forces, the torque (B) was calculated and equal to 12000 N mm, and at the point of connection with the machine, it was clamped (C) (Figure 3).

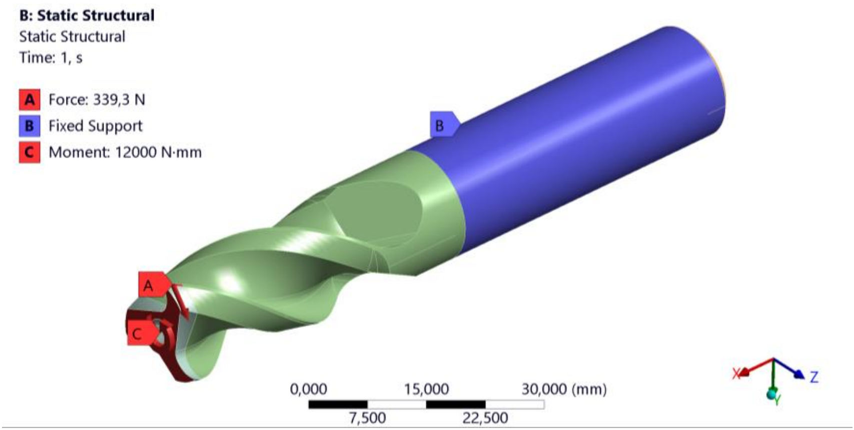
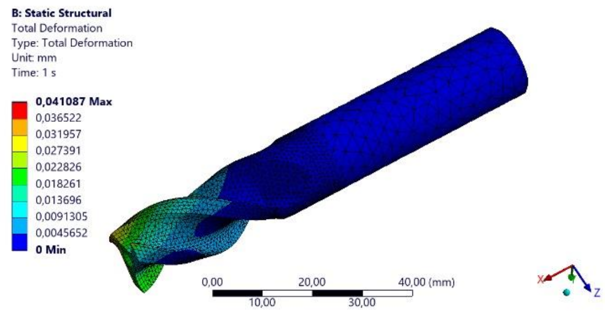


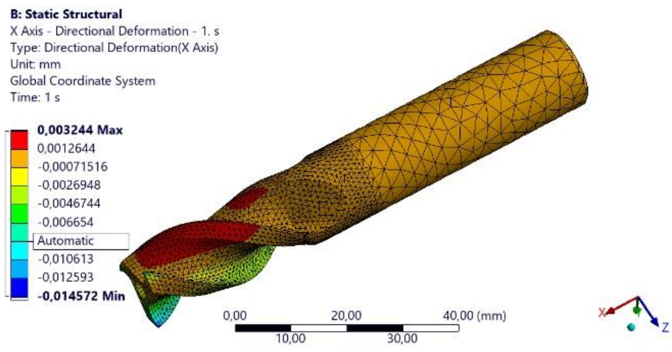
Figure 3. End mill boundary conditions

Analysis of results

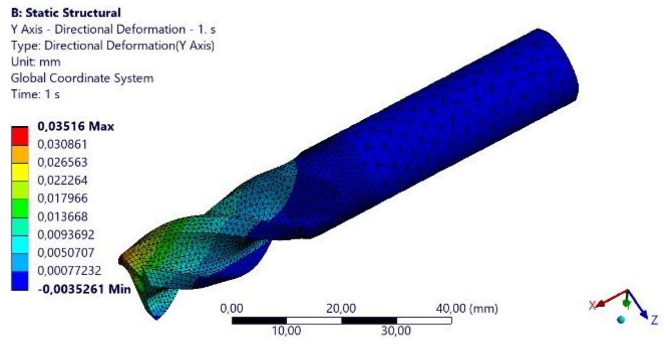
After running the solver, the results can be obtained. Figure 4 illustrates the deformations of the end mill, with the maximum total deformation reaching 41 μm.



а)



б)



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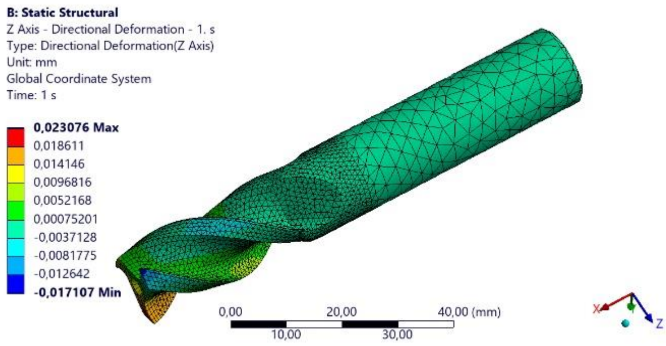

г)

Figure 4. Deformations of the end mill: a) total; b) along the X axis; c) along the Y axis; d) along the Z axis

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The deformation along the X axis was – 14.6 μm, along the Y axis – 35 mm and along the Z axis -23 μm.

Figure 5 shows the equivalent von Mises stress and it is noticeable that the stress concentration occurs at the end of the cutting edge and reaches 1352 MPa. And this indicates the occurrence of wear of the cutting edge.

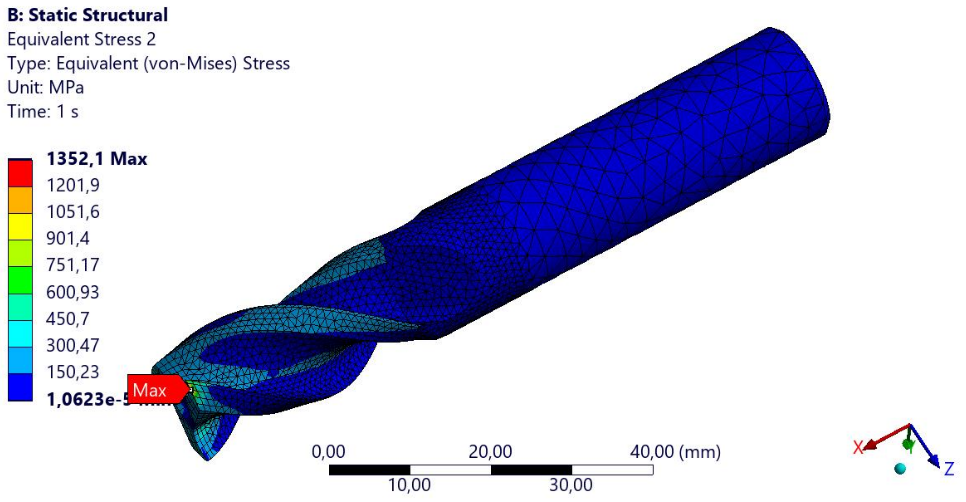

Figure 5. Equivalent stress according to von Mises

The shear stress in the YZ plane at the cutting edge also reached a maximum value of 608 MPa (Figure 6).

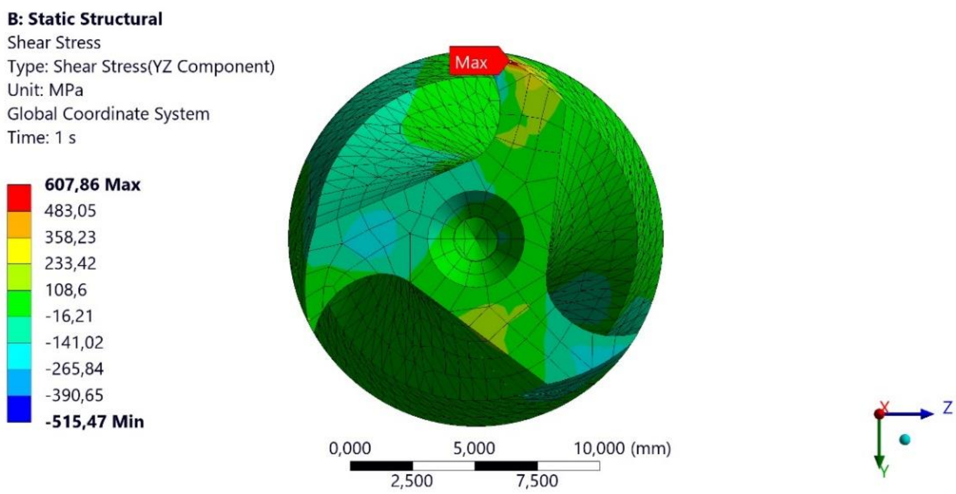

Figure 6. Shear stress in the YZ plane

Conclusions

Based on the results of the strength calculations, the total deformation and its components along the X, Y, and Z axes were obtained. The total deformation was measured at – 41 µm.

The calculations confirmed that at spindle speeds exceeding $n_{sp} \geq 6000–7000$ rpm, wear occurs at the cutting edge, with an equivalent von Mises stress of – 1352 MPa and a shear stress of 608 MPa. It is therefore recommended that processing should not exceed spindle speeds of $n_{sp} \geq 6000–7000$ rpm.

The contribution of the authors.

B.S. Donenbaev – development of the calculation model, interpretation and processing of results.

K.T. Sherov – review of existing methodologies, research of the state of the problem and conclusions.

S.Sh. Magavin – concept, methodology and text correction.

A.K. Rakishev – experiment, calculation of cutting force components and analysis.

L.N. Makhmudov – development of the calculation scheme, data collection and processing.

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Қиын өңделетін материалдарды өңдеу үрдісіндегі құралдың кернеулі деформацияланған күйін модельдеу

Аңдатпа. 15Х12ВМФ ыстыққа төзімді жоғары легирленген болатты өңдеу кезінде саусақты жонғыштың кернеулі деформацияланған күйін зерттеу реті қарастырылған. Зерттеу келесі кезеңдерден тұрады: саусақты жонғыштың 3D геометриясын құру, материалды тағайындау, ақырлы-элементтікке бөлу, шекаралық шарттарды беру және шешім нәтижелерін талдау. Кесу күштерінің құрашылары бұрандалы кесу жиегінің дайындамамен тікелей жанасу аймағына түсіріледі, ал айналу момент кескіш осіне қатысты әсер етеді. Кесу күштерінің құраушылары мен айналу моменті дағдарыс кесу режимдерінде есептелді. Беріктікті есептеудің есептік көрсеткіштері саусақты жонғыштың жобалау есептерінде қолданыла алады.

Кілт сөздер: жоғары жылдамдықты фрезерлеу, саусақты жонғыш, ақырлы-элемент, кернеу, деформация, ыстыққа төзімді болат.

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Моделирование напряженно-деформированного состояния инструмента в процессе фрезерования труднообрабатываемых материалов

Аннотация. Рассмотрена последовательность исследование напряженно деформированного состояния концевыми фрезамы при обработке жаропрочной высоколегированной стали 15Х12ВМФ. Исследование состоит из следующих этапов: создание 3D геометрии концевой фрезы, назначение материала, разбиение на конечные элементы, задание граничных условии и анализ результатов решения. Составляющие сил резания приложены на непосредственный участок контакта винтовой режущей кромки с заготовкой, а крутящий момент приложен относительно оси фрезы. Составляющие сил резания и крутящий момент были вычислены в критических режимах резания. Расчетные показатели прочностного расчета могут быть использованы в задачах проектирования концевых фрез.

Ключевые слова: высокоскоростное фрезерование, концевая фреза, конечный элемент, напряжение, деформация, жаропрочный сталь.

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