A Study on Surface Quality and Stress-State in Rotational Turning of Steel 45 Using Experimental and FEM Approaches

Karibek T. Sherov
S. Seifullin Kazakh Agrotechnical Research University, Astana, Kazakhstan
k.sherov@kazatu.kz

Zhanara K. Mussina
Toraighyrov University, Pavlodar, Kazakhstan
mussinazhanara@gmail.com (corresponding author)

Almat A. Sagitov
S. Seifullin Kazakh Agrotechnical Research University, Astana, Kazakhstan
a.sagitov@kazatu.kz

Galiya T. Itybayeva
Toraighyrov University, Pavlodar, Kazakhstan
itybaeva.g@tou.edu.kz

Assylkhan V. Mazdubay
Toraighyrov University, Pavlodar, Kazakhstan
mazdubay.a@teachers.tou.edu.kz

Aibek K. Sherov
S. Seifullin Kazakh Agrotechnical Research University, Astana, Kazakhstan
kbstepns@gmail.com

Dinara Sh. Kossatbekova
S. Seifullin Kazakh Agrotechnical Research University, Astana, Kazakhstan
d.kosatbekova@kazatu.edu.kz

Sayagul O. Tussupova
Toraighyrov University, Pavlodar, Kazakhstan
tussupova.s@teachers.tou.edu.kz

Assylbek Zh. Kassenov
Toraighyrov University, Pavlodar, Kazakhstan
kassenov.a@tou.edu.kz

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ABSTRACT

This study investigates a method for the rotational turning of external cylindrical surfaces with a particular focus on evaluating the quality of the machined surface and its stress state during the turning of 45 steel, using experimental methods and the Finite Element Method (FEM). The influence of the cutting

modes on the quality indicators during rotary turning was analyzed, and their optimal values for the processing of steel 45 were determined. The results indicate that an increase in the spindle speed has a positive impact on the roughness of the machined surface, but a negative effect on hardness. Increasing the feed rate has an ambiguous impact on the quality indicators of the machined surface: it improves the roughness but reduces the hardness. With an increase in the cutting depth, both quality indicators deteriorate. In addition, using the ANSYS/LS-DYNA (Ls Pre-Post) software package, the stress-strain state of the steel 45 workpiece was calculated, and the temperature change in the cutting zone, in the chips, and on the machined surface during rotational turning was determined. This revealed that the maximum equivalent Mises stress is 1.1 MPa and the maximum temperature in the cutting zone is 287 °C. It was observed that when the cutting force fluctuates within the range of 4.8 kN-5.1 kN, the vibration occurring in the cutting zone is reduced. The results of this study indicated that rotary machining allows for increased feed, depth, and cutting speed without critical tool wear, which directly increases the productivity. It also reduces the tooling, energy, machining time, and rework costs, resulting in significant economic benefits.

Keywords-rotational turning; roughness; hardness; cutting conditions; temperature; stress-strain state; cutting force

I. INTRODUCTION

Improving the finishing operations, which play a decisive role in determining the operational properties of the parts, is crucial for solving the essential problem of increasing the efficiency, reliability, and quality of manufactured machines. Despite the significant progress in the technological development for the manufacturing parts without chip removal, blade processing will still be the most affordable and universal method, ensuring the production of parts of the required quality. The cutting efficiency can be increased by using new tool materials or various hardening methods, optimizing the composition of the cutting fluids, tool geometry, etc. Various combined processing methods are also known to allow the process to be intensified, but they usually require very significant costs, and the design of such installations is more complex. The resources of the tool materials and methods for increasing the tool life are close to their practical limits. There is an urgent need to find fundamentally new principles for designing cutting schemes that will significantly increase the efficiency and quality of blade processing. An example of such a method is rotational cutting, which is based on the idea of the constant periodicity of the cutting-edge and the reduction of friction on the contact surfaces of the tool. This is achieved by giving the cutting-edge a circular shape around the axis. Rotational machining methods have been increasingly used since the 1970s. Currently, these methods are being researched widely by scientists in Germany, Ukraine, the USA, Belarus, and Japan.

Authors in [1] considered various options for the chip removal in turning operations based on the kinematic schemes used. The interest in these options has grown significantly, since the development of cutting tools with geometrically defined cutting-edges and new tool materials has made it possible to replace grinding with turning even when machining hardened surfaces. It is particularly relevant for finishing operations, where achieving the required functional surface topography and selecting the appropriate technology are crucial. One of these technological variants, rotational turning, was selected as the subject of this study. Unlike traditional turning with a single-point tool, in rotational turning, cutting is performed by a long, inclined, and spatially oriented cutting edge. The slow rotation of the large-diameter edge creates a material cutting mechanism, like the planning process. The geometric conditions for calculating the tool rotation angles required for the cutting-in, exit, and constant machining phases were determined. A method for calculating these angles was also proposed. The design of the tool used was described in detail, the permissible technological parameters were given, and the high productivity of the method was demonstrated.

Authors in [2] investigated a progressive chip-forming machining technology – rotational turning – which uses a tool with a predetermined cutting-edge geometry. In some cases, this technology can replace traditional finishing methods based on the tool's application with undefined cutting-edge geometry. The influence of the cutting conditions during rotational turning on the machined surface roughness was discussed and the experimentally obtained roughness parameters were compared with their theoretical calculations. Considering that rotational turning is a new machining technology with an original kinematic scheme and a non-typical cutting tool geometry, special attention is paid to the method of measuring the roughness after machining by a nonlinear cutting-edge. The experimental studies and their evaluation were carried out using a roughness parameter determination method. The results obtained demonstrate the extent to which the actual process correlates with empirical dependencies.

A method proposed in [3] combines elements of oblique turning (in which the layer being cut moves along the cutting-edge) and rotational turning (in which sections of the cutting-edge are constantly renewed). This combination improves the cooling in the cutting zone and, as a result, increases the tool service life. To ensure the required cutting speed, it is proposed to select the appropriate number of cuts per min, with the rotation of the workpiece shaft acting as the rotational feed.

The influence of the geometric and technological parameters of the multi-faceted cutting tool rotational turning method on the surface finish quality was investigated in [4, 5]. Using numerical, analytical, and experimental methods, the effect of the cutting conditions on the roughness parameters was determined. As a result, semi-empirical dependencies were obtained, allowing cutting conditions to be assigned with predictable roughness parameters Ra, Rz, and Rmax. Using different cutting-edge geometries and corresponding cutting parameters reduces the contact time between the tool and the workpiece, therefore reducing the friction forces, and lowering the tool temperature. Controlling the tool inclination angle and using a minimum amount of coolant also helps to decrease the adhesion effect.

Rotational cutting processes have also been studied [6-8], ensuring the renewal of the contact surfaces of the cup cutter. The conditions under which the sliding friction is replaced partially by the rolling friction, which increases the tool life, have been determined. Rotational cutting is also accompanied by an increase in the length of the cutting edge, parts of which periodically participate in the removal of stock from the workpiece and are cooled outside the cutting zone, increasing the durability of the rotational tool [3, 9].

Modern methods also make a significant contribution to the development of the processing technologies. In [10], a study was conducted on Ultrasonic-Assisted Turning (UAT) of small shafts made of C40 carbon steel and 201 stainless steel at three cutting speeds (15, 24, and 36 m/min) with constant feed and cutting depth. It was found that for C40 steel, the method provides a reduction in the Ra parameter of up to 308% at 15 m/min, while for 201 steel, the improvement does not exceed 23%. In [11], an analytical description of three high-feed turning processes was presented: skiving, tangential turning, and rotary turning using structural-geometric modeling. The reliability of the obtained equations of motion was experimentally confirmed, and directions for further research were outlined. Authors in [12] described a rotary turning technology that combines hard turning and circular milling for the machining of hardened parts. The developed analytical model showed that the effective radius at the tool tip exceeds the similar parameter in traditional hard turning by more than 50 times, which makes it possible to virtually eliminate the feed marks. It has been experimentally established that the minimum surface roughness in this process is determined not by the feed, but by factors, such as the waviness of the cutting edge. In [13], turning with an Actively Driven Rotary Tool (ADRT) was studied, taking into account thermal aspects; it was found that during the dry machining of AISI 304 steel, the tool temperature decreases from 730 °C to 640 °C when the rotation speed is increased from 10 to 200 m/min.

An analysis of these studies shows that there is considerable potential for improving the durability of cutting tools and the quality of the rotational cutting surfaces, when compared to traditional blade and abrasive cutting technologies.

It should also be noted that the Republic of Kazakhstan does not have its own tool manufacturing facilities, and mechanical engineering enterprises have to purchase metal-cutting tools at high prices from foreign manufacturers. All this leads to an increase in the cost of mechanical operations and, ultimately, in the cost of manufactured products.

This problem can be solved by creating new designs for cutting tools and developing resource-saving, high-quality methods of mechanical processing that improve the quality of processing and the wear resistance of cutting tools and increase their service life. This will have a positive effect on reducing the production costs.

II. RESEARCH METHODOLOGY AND EQUIPMENT

The research methodology is based on the principles of the mechanical engineering technology, cutting theory, cutting tool design, metal technology, and materials science. Experimental studies were conducted to establish the influence of the cutting conditions on the quality indicators in rotational turning. In addition, the ANSYS/LS-DYNA (Ls Pre-Post) software package was used to calculate the stress-strain state during the rotary turning of steel 45 workpieces and to determine the temperature change in the cutting zone, in the chips, and on the machined surface. The experimental studies were carried out on a 1K62 screw-cutting lathe.

The technological equipment used in experimental studies is shown in Figure 1. Figure 2 portrays the rotational turning process of steel 45.

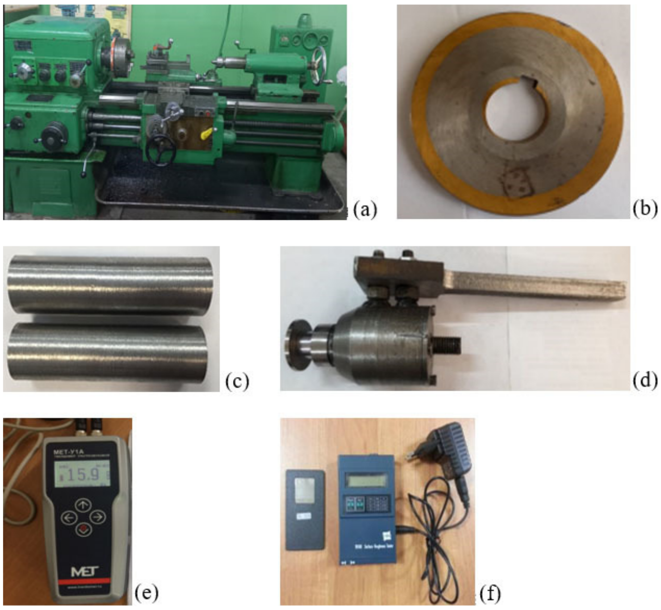

Fig. 1. Technological equipment used in experimental research: (a) screw-cutting lathe, (b) cup cutter made of R6M5, (c) workpiece made of steel 45, (d) special rotary tool, (e) MET-U1 device for measuring hardness, and (f) TR 100 profilometer for measuring roughness.

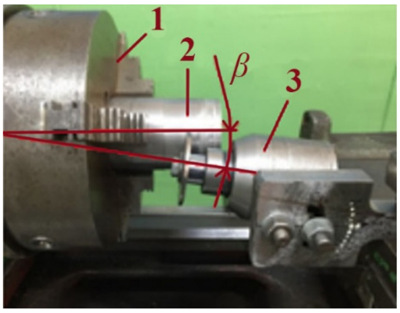

Fig. 2. Rotational turning process of steel 45: (1) three-jaw chuck, (2) workpiece, (3) rotational tool; *(β)* angle of installation of the cup cutter.

III. RESULTS

During the experimental studies, the cup cutter angle was set to β=10°, as proposed in [9, 10], and remained constant. Figures 3 and 4 display the influence of the spindle speed on the quality indicators at different feed rates. Figures 5 and 6 illustrate the influence of the spindle speed on the quality indicators at different cutting depths.

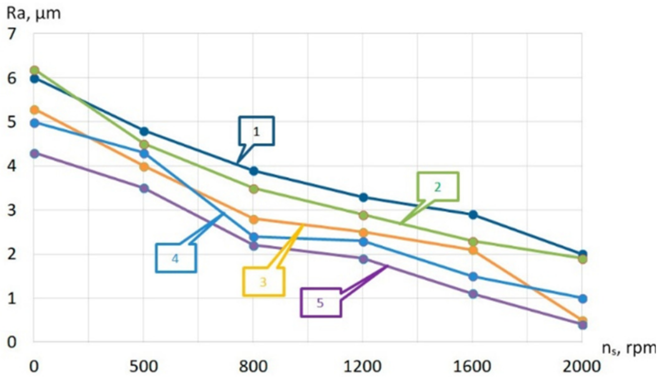

Fig. 3. The effect of the spindle speed on the roughness of the machined surface at different feed rates, for β=10^0, t=1.5 mm: (1) f_1=1.04 mm/rev, (2) f_2=0.57 mm/rev, (3) f_3=0.28 mm/rev, (4) f_4=0.14 mm/rev, (5) f_5=0.07 mm/rev.

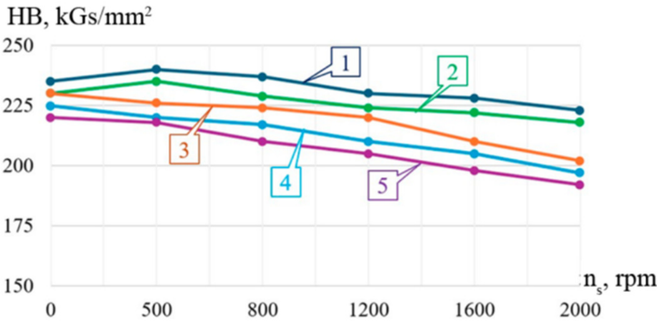

Fig. 4. The effect of the spindle speed on the hardness of the machined surface at different feed rates, for β=10^0, t=1.5 mm: (1) f_1=1.04 mm/rev, (2) f_2=0.57 mm/rev, (3) f_3=0.28 mm/rev, (4) f_4=0.14 mm/rev, (5) f_5=0.07 mm/rev.

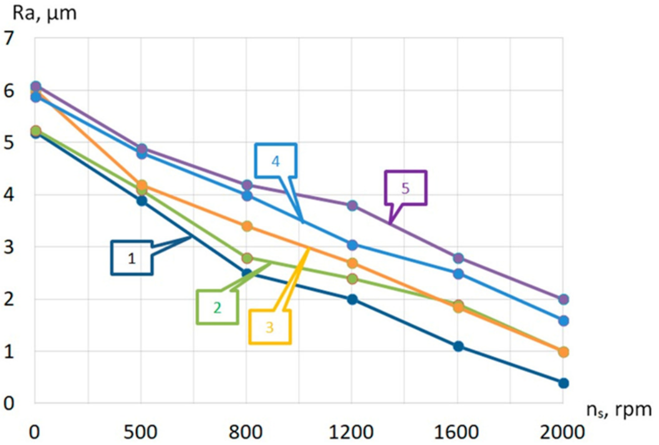

Fig. 5. Graphs showing the effect of the spindle speed on the roughness of the machined surface at different cutting depths, for β=10^0, f=0.28 mm/rev: (1) a_1=0.5 mm, (2) a_2=1.0 mm,(3) a_3=1.5 mm, (4) a_4=2.0 mm, (5) a_5 =2.5 mm.

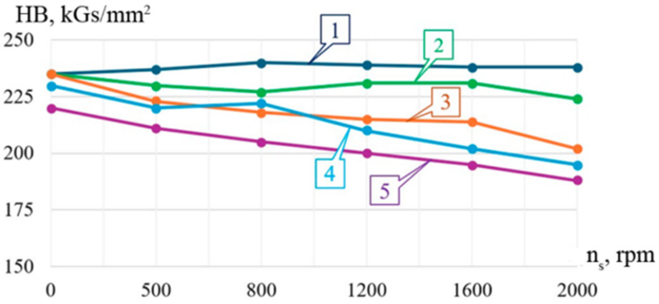

Fig. 6. The effect of the spindle speed on the hardness of the machined surface at different cutting depths for β=10^0, f=0.28 mm/rev: (1) a_1=0.5 mm, (2) a_2=1.0 mm,(3) a_3=1.5 mm, (4) a_4=2.0 mm, (5) a_5 =2.5 mm.

IV. DISCUSSION

The cutting mechanism in rotary machining with self-rotation of the cutting tool (when the tool rotates around its axis and simultaneously moves relative to the workpiece) is based on the interaction of the rotating tool with the workpiece being machined in which material is removed by the contact forces and mechanical stretching.

The experimental studies on the influence of the cutting modes on the quality indicators during the rotational turning of steel 45 indicated that increasing the spindle speed has a positive effect on the machined surface roughness (Figures 3 and 5), but a negative impact on hardness (Figures 4 and 6).

The decrease in roughness can be a result of the reduced influence of vibrations and cutting interruptions, since the cutting frequency increases at high speeds and the amplitude of vibrations relative to the cutter trajectory diminishes. The high cutting frequency prevents the vibrations from forming deep scratches, resulting in a smoother surface. It is also worth noting that micro-irregularities formed by previous passes of the cutting edge are partially cut off or plastically deformed by subsequent passes. This gives the effect of additional smoothing, almost like grinding.

The reduction in hardness of the machined surface can be explained by the fact that as the spindle speed increases, the time and force of the edge's impact on a single point of the surface decrease, cold plastic deformation (work hardening) diminishes, and short-term heating partially removes the hardening.

It was also found that with an increase in the cutting depth, both quality indicators deteriorate (Figures 5 and 6)

It is assumed that as the cutting depth increases, the cutting forces and the thickness of the removed layer increase, which intensifies cold plastic deformation and vibrations, having a negative effect on the hardness and roughness of the machined surface.

An increase in feed has an ambiguous effect on the quality indicators of the machined surface: roughness improves (Figure 3), whereas hardness decreases (Figure 4).

The improvement in the quality of the machined surface can be attributed to the fact that as the feed rate increases, the tool rotates faster, the edges overlap the cutting marks more tightly and cut off the irregularities, thus reducing roughness. The decrease in hardness occurs because, with a higher feed rate, the tool rotates faster, the contact time of the edge with a single point on the surface is reduced, the cold plastic deformation is reduced, the work hardening is weaker, and as a result, the hardness of the machined layer decreases.

Thus, the following optimal cutting parameters were established: $\beta=10^0$; $a=1.5$ mm; $f=0.28$ mm/rev; $n=2000$ rpm. When machining at the optimal cutting parameters, $R_a=1$-0.5 µm (Figure 3(a), curve 3; Figure 4(a), curve 3) and HB200-210 (Figure 3(b), curve 3 and Figure 4(b), curve 3) are achieved.

A. *Modeling the Process of Cutting a Workpiece with a Rotational Cup Cutter*

The ANSYS/LS-DYNA (Ls Pre-Post) software package is used to calculate the stress-strain state when cutting workpieces made of steel 45 with a cup cutter.

In this work, the Smooth Particle Method (SPH) [14] is used to calculate the stress-strain state of the chip formation zone when cutting steel 45 workpieces. In the numerical modeling of the metal cutting processes, important tasks include the correct reproduction of large plastic deformations, intense heating, chip breakage, and the formation of new free surfaces. In the traditional FEM, the calculation area is discretized by a mesh, which is well suited for elastic and moderately plastic deformations. However, when modeling cutting, the metal is subjected to extreme deformations and local destruction, which leads to a severe degradation of the grid and requires frequent remeshing, increasing the computational costs and creating the risk of loss of accuracy. SPH is mesh-free and operates with a particle system, which avoids the problems associated with remeshing. The particles naturally follow the material flow, correctly describing the process of chip formation, the formation and evolution of the shear zone, and the contact between the tool and the workpiece. In addition, SPH copes well with tasks where there are discontinuities and complex boundaries, without the need to introduce special algorithms to track the material boundary. According to SPH, the workpiece is represented by discrete elements called particles. These particles are characterized by a spatial distance or "smoothing length," usually represented in equations by the parameter h. The value of h characterizes the distance at which the properties of the particles are "smoothed." This means that any physical parameter of any particle is obtained by summing the corresponding values of all particles located at a distance of 2h from it.

For example, the temperature at point t depends on the temperature of all particles at a distance of 2h from t. The influence of each particle on the properties is estimated according to its density and according to the distance from it/its distance to the particle of interest. Mathematically, this is described by a kernel function. The Gaussian function is often used as the kernel function. This principle of proximity allows for savings in computational resources by eliminating the relatively small influence of the distant particles. The value of any physical quantity A at point X is given by:

$$\mathrm{A(X)} = \sum_j m_j \frac{A_j}{\rho_j} W(|X - X_j|, h) \qquad (1)$$

where m_j is the mass of particle j, A_j is the value of A for particle j, ρ_j is the density associated with particle j, and W is the kernel function.

By assigning each particle its own smoothing length and allowing it to change over time, the simulation resolution can be adjusted to the local conditions.

The results of the cutting process calculations performed using SPH [14] indicate that this method is convenient in the case of strong deformations and that it fully reflects the chip separation process. At the same time, the time spent on calculations is equal to or slightly less than that when using the FEM, which involves frequent mesh restructuring and uses the Lagrange-Euler ALE formulation.

B. *General Model Parameters*

For the research in the Ls Pre-Post CAD system based on geometric parameters (Table I), a solid model of a cup cutter was constructed (Figure 7).

TABLE I. GEOMETRIC PARAMETERS OF THE CUP CUTTER DRILL

Parameter	Value
Cup cutter diameter	40 mm
Rear angle	7 degrees
Cup cutter thickness	3 mm
Material	R6M5

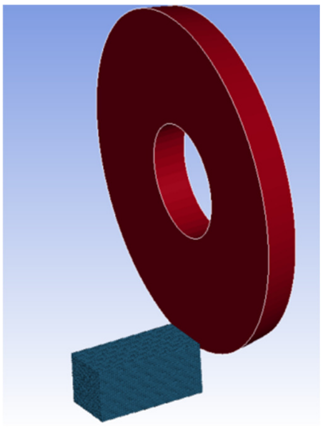

Fig. 7. Solid model of a cup cutter.

C. *Simulation of the Rotational Turning Process in LS-DYNA Using SPH*

The RIGID (absolutely rigid material) model of the cutting tool (cup cutter) was used in the calculations to reduce the processing time. High-speed steel R6M5, which is the Russian equivalent of foreign high-speed steel class M2, was utilized as the drill material.

The workpiece model is a parallelepiped with dimensions of 15x15x40 mm. The constraints limiting the movement of the workpiece were applied to its side surface. The cutting process was calculated until the cutting tool passed through the workpiece. The Johnson-Cook model was used to simulate the plastic deformation and material failure, which allows the kinematic hardening and adiabatic heating of the deformed material. The critical value of shear deformation in the layer separating the workpiece and the chip was selected as the chip separation criterion. Combined cutting was simulated, and the tool feed was considered the cut width. As a result of the simulation, the stress and deformation fields of the machined material, as well as the thermal field of the chip and the machined product, were obtained. One of the most well-known models describing the behavior of metal during plastic deformation is the Johnson-Cook model in the form of the Mi-Grunaisen equation of state. This model considers both the kinematic hardening and adiabatic heating of the deformed material in the dependence form of the stress on deformation rate and temperature. In this model, the equivalent plastic stress is determined by:

$$\sigma = (\mathrm{A} + \mathrm{B} \cdot \bar{\varepsilon}^{\mathrm{n}}) \cdot (1 + \mathrm{C} \cdot \ln \cdot \dot{\varepsilon}^{*}) \cdot (1 - \mathrm{T}^{*\mathrm{m}}) \quad (2)$$

$$\dot{\varepsilon}^{*} = \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0} \quad (3)$$

$$\mathrm{T}^{*} = \frac{\mathrm{T} - \mathrm{T}_0}{\mathrm{T}_\mathrm{m} - \mathrm{T}_0} \quad (4)$$

where A is the yield strength under slow loading; B is the isotropic (static) hardening, characterizing sensitivity to deformation; $\bar{\varepsilon}$ is the equivalent plastic deformation; n is the coefficient representing the hardening effect; C is the coefficient of sensitivity to the deformation rate; $\dot{\varepsilon}$ is the plastic deformation rate; $\dot{\varepsilon}_0$ is the deformation rate during static tests; T_0 and T_m are the ambient temperature and melting temperature of the material, respectively; and m is an exponent that takes into account the phenomenon of thermal softening of the material.

In (2), the first factor describes the work hardening phenomenon, the second describes the dynamic hardening, and the third describes the phenomenon of thermal softening. To model the chip separation from the machined surface, the Johnson-Cook conjugate model was used as the material failure criterion, which describes the damage history of each element based on the cumulative damage accumulation law D:

$$\mathrm{D} = \sum \frac{\Delta\bar{\varepsilon}}{\varepsilon_\mathrm{f}} \quad (5)$$

where $\Delta\bar{\varepsilon}$ is the increment of effective plastic deformation during the integration cycle; ε_f is the equivalent deformation of failure under the current conditions of deformation temperature, pressure, and equivalent stress. Failure occurs if the damage parameter D exceeds the value of unity, $D \geq 1$. The deformation-failure process is determined by the ratio:

$$\varepsilon_\mathrm{f} = \left(\mathrm{D}_1 + \mathrm{D}_2 \cdot \exp\left(\mathrm{D}_3 \cdot \frac{\mathrm{p}}{\mathrm{q}}\right)\right) \cdot \left(1 + \mathrm{D}_4 \cdot \ln \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right) \cdot \left(1 + \mathrm{D}_5 \frac{\mathrm{T} - \mathrm{T}_0}{\mathrm{T}_\mathrm{m} - \mathrm{T}_0}\right) \quad (6)$$

where D_1, D_2, D_3, D_4, D_5 are the material failure parameters; p is the hydrostatic pressure; and q is the Mises stress.

Failure deformation depends on the effective strain rate $\dot{\varepsilon}^{*}$, the stress state stiffness coefficient determined by the ratio of hydrostatic pressure to Mises stress, and temperature. The material parameters D_1, D_2, D_3 characterize the ratio of the hydrostatic pressure, or average stress, to the equivalent Mises stress, parameter D_4 considers the influence of the deformation rate on failure, and parameter D_5 determines the influence of the temperature on deformation during failure.

The ANSYS software package was used to simulate the cutting process. Its Ls Pre-Post application contains the Johnson-Cook model and allows the complex behavior of the material under dynamic loading to be simulated. Experimental data on the dynamic properties of the material under investigation are required to determine the parameters of the Johnson-Cook model and the failure criteria. In this work, steel 45 was selected for the study. The physical and mechanical properties of the workpiece and tool material are presented in Table II, and the parameters of the Johnson-Cook model are depicted in Tables III and IV [15].

TABLE II. PHYSICAL AND MECHANICAL PROPERTIES OF THE WORKPIECE AND TOOL MATERIAL

Material	Steel 45
Density, kg/m^3	7850
Young's modulus, Pa	$2 \cdot 10^{11}$
Poisson's ratio	0,29
Specific heat capacity, J/(kg·°C)	486
Thermal conductivity coefficient, W/m·°C	52

TABLE III. JOHNSON-COOK MODEL PARAMETERS FOR STEEL 45, CHARACTERIZING THE CONDITIONS OF PLASTIC DEFORMATION

A, Pa	**B, Pa**	**n**	**C**
$616 \cdot 10^6$	$668 \cdot 10^6$	0,225	0,0134
m	**$\dot{\varepsilon}_0$**	**T_m, °C**	**T_0, °C**
1.078	1	1,350	22

TABLE IV. JOHNSON-COOK MODEL PARAMETERS FOR STEEL 45, CHARACTERIZING THE CONDITIONS OF FRACTURE

D_1	**D_2**	**D_3**	**D_4**	**D_5**
0.04	1.03	1.39	0.002	0.46

When modeling the friction conditions at the chip-tool and tool-workpiece contact sites, a model based on Coulton-Amonton's law was used:

$$\mathrm{F} = \mu \cdot \mathrm{N} \quad (7)$$

where μ is the Coulomb friction coefficient, N is the normal reaction force. Based on an analysis of literature sources, the friction coefficient was taken to be $\mu=0.22$.

The initial conditions for determining the characteristics of the thermal field were set as: workpiece surface temperature – 20°C, specific heat capacity of steel 45–473 J/(kg·°C), thermal conductivity of steel 45–48 W/(m·°C).

The following results were obtained during modeling (at cutting conditions: $n_{sp}=630$ rpm, $f=0.3$ mm/rev, $a=1$ mm, at workpiece temperature $T_0=20$°C) for the equivalent Mises stress (Figure 8) and heat field in the workpiece (Figure 9).

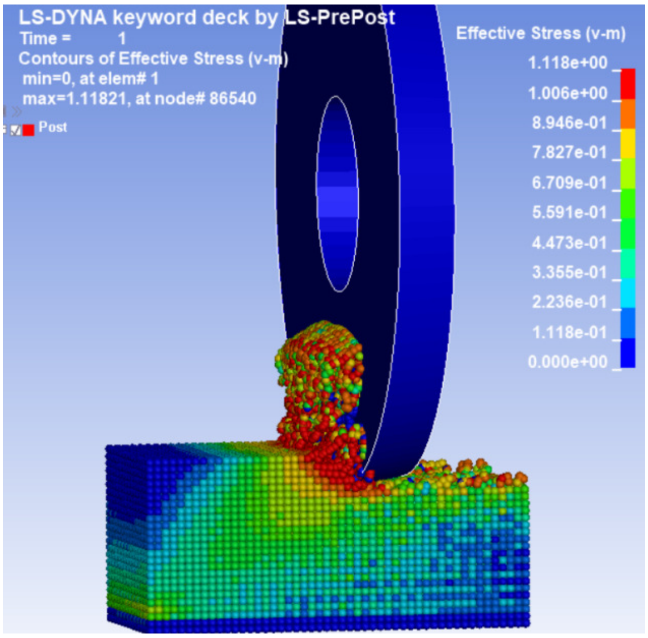

Fig. 8. Equivalent stress of Mises.

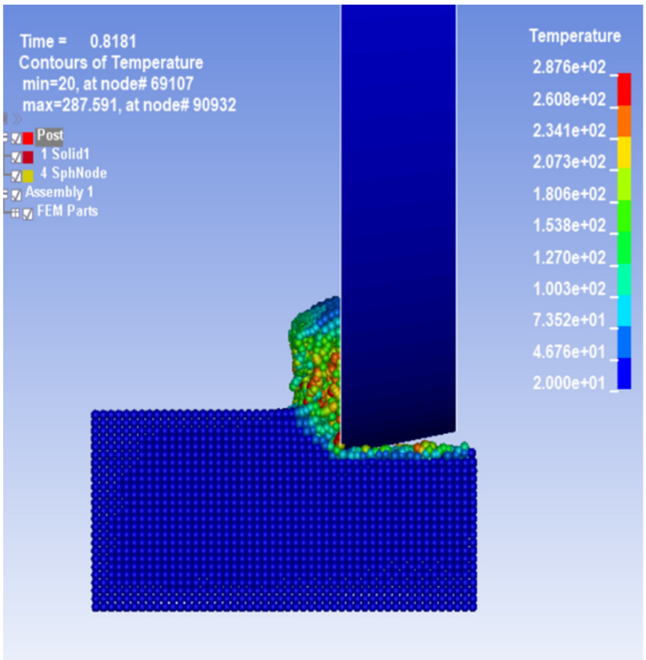

Fig. 9. Temperature change.

Using the Ls Pre-Post program, graphs of the total cutting force (Figure 10) and temperature changes in the cutting zone, in the chips, and on the machined surface (Figure 11) were also constructed.

The results show that the maximum equivalent Mises stress is 1.1 MPa, and the maximum temperature in the cutting zone is 287 °C. The graph of the total cutting force demonstrates that the cutting force at the moment of penetration is the highest (6.8 kN) and then decreases to 4.6 kN. Further in the machining process, the cutting force fluctuates between 5.1 kN and 5.9 kN. This means that vibration occurs in the cutting zone, which negatively affects the quality of the machined surface.

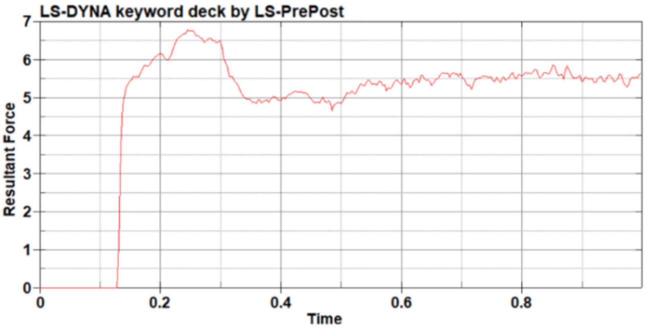

Fig. 10. Change in total cutting force.

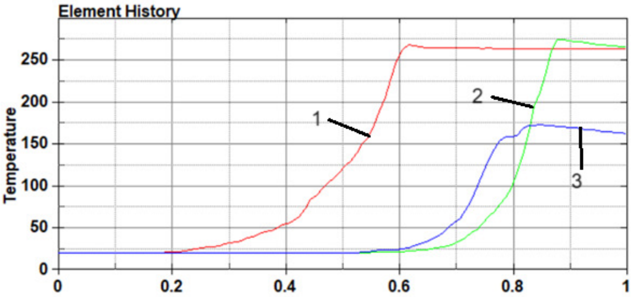

Fig. 11. Temperature change: (1) in the cutting zone, (2) in the chips, and (3) on the machined surface.

It is also observed that at a workpiece temperature of T_0=80ºC, the cutting force at the moment of penetration is the highest (6.5 kN), then decreases to 4.5 kN, and after that fluctuates from 5 kN to 5.5 kN. When the workpiece is heated to T_0=120ºC, the cutting force at the moment of penetration is at its maximum (6.2 kN), then decreases to 4.4 kN, before fluctuating in the range of 4.8 kN-5.3 kN. When the workpiece is heated to T_0=180ºC, the cutting force at the moment of penetration is at its maximum value (5.8 kN), then decreases to 4.2 kN, and later fluctuates from 4.8 kN to 5.1 kN. This means that the vibration occurring in the cutting zone decreases.

The simulation of the metal cutting process using the ANSYS/LS-DYNA (Ls Pre-Post) program and the Johnson-Cook model to display the plastic deformation and material failure allows obtaining the stress and deformation fields of the processed material, as well as the thermal field of the chips and the processed product. The results obtained are in good agreement with the data known in the literature obtained experimentally and do not contradict the traditional provisions of the cutting theory. The proposed simulation method allows investigating the stress-strain and thermal state of the cutting process, the conditions of the chip formation, and predicting the quality parameters of the surface layer.

V. CONCLUSIONS

1. The analysis of the scientific results obtained from studying methods of rotational machining showed that

these approaches have a great potential for increasing the durability of the cutting tools and the quality of the machined surface compared to traditional technologies – blade and abrasive machining.

2. Experimental studies have established the patterns of the influence of the cutting conditions on the roughness and hardness of the machined surface during the rotational turning of steel 45.
3. The stress-strain state of a steel 45 workpiece during rotational turning was calculated using the ANSYS/LS-DYNA (Ls Pre-Post) software package, and it was established that the maximum equivalent Mises stress is 1.1 MPa and the maximum temperature in the cutting zone is 287 °C. It was also found that when the cutting force fluctuates within the range of 4.8 kN-5.1 kN, the vibration occurring in the cutting zone is reduced. The proposed simulation method allows investigating the stress-strain and thermal state of the cutting process and chip formation conditions, as well as predicting the quality parameters of the surface layer.
4. It has been established that the following factors have a positive effect on productivity during rotary machining:

- High cutting speeds without tool overheating –self-rotation distributes the heat evenly across the entire cutting edge.
- Use of several sections of the cutting edge –the wear is distributed, the edge remains sharp longer, and it is possible to work at higher speeds.
- Reduction of cutting forces –the tool enters the material at a variable angle, and the cutting is smoother, which allows for increased feed and cutting depth.
- Simultaneous improvement in surface quality –less need for additional finishing passes.

And the reduction in the production costs is achieved by:

- Increasing tool durability –the wear is distributed across the entire edge, the cutting elements last longer, and replacement and regrinding costs are reduced.
- Reduced processing time –it is possible to work at higher speeds and feeds, reducing the number of passes and overall machine time.
- Reduced energy consumption –a smoother cutting process requires less effort, which means less energy consumption by the machine.
- Less waste –an improved surface quality reduces the cost of reworking or additional grinding.
- Optimization of equipment fleet –combining roughing and finishing in a single pass reduces the need for additional operations and machines.

5. Further research plans include modifying the tool design to reduce the risk of vibration by installing a damping element in the bearing assembly of the rotary tool.

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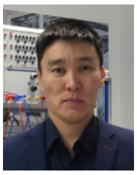
AUTHORS PROFILE

K. T. Sherov, Doctor of Technical Sciences, Academician of the Kazakh National Academy of Natural Sciences, Member of the International Union of Mechanical Engineers, Professor of the Department of Technological Machines and Equipment.

Zh. K. Mussina, Candidate of Technical Sciences, Associate Professor. She was born in 1976 in Kazakhstan. Education: S. Toraighyrov Pavlodar State University, degree in Metal-Cutting Machines and Tools (1998). She defended her Candidate's dissertation entitled "Improving the Quality of Hole Machining by Developing a New Drill Design" under the supervision of Professors T.M. Mendebayev and N.S. Dudak (Almaty) in 2010. Author of 14 patents for inventions and 100 research papers and teaching notes.



A.A. Sagitov, PhD, senior lecturer. He was born in 1990 in Kazakhstan. Education: Karaganda State Technical University, specialty 5B071200–"Mechanical Engineering" (2012). He defended his PhD dissertation entitled "Development of a combined method of multi-blade rotational surface treatment of mating parts" supervised by Professor K.T. Sherov (Karaganda) (2023). He holds patents for 8 inventions, about 30 scientific papers and teaching notes.

G. T. Itybayeva, Candidate of Engineering Sciences, Associate professor. She was born in 1961 in Kazakhstan. Education: Karaganda Polytechnic Institute of the Order of the Red Banner of Labor, specialty "Mechanical Engineering" (1984). She defended her Candidate's dissertation entitled "Improving the quality of processing cylindrical holes using a new countersink-broaching design" supervised by Professors T.M. Mendebayev and N.S. Dudak (Almaty) (2010). She holds patents for 13 inventions, about 100 scientific papers and teaching notes.

A. V. Mazdubay, Doctor of Philosophy, Associate Professor. Born in 1984 in Kazakhstan. Education: Pavlodar State University named after S. Toraigyrov, specializing in "Metallurgical Machines and Equipment" (2006). He defended his dissertation in specialty 6D071200 - "Mechanical Engineering" on the topic "Research and development of a resource-saving method for cutting metal blanks" under the supervision of Professor K.T. Sherov (Karaganda) (2018).

A. K. Sherov, PhD, senior lecturer. He was born in 1985 in Kazakhstan. Education: Ташкентский государственный технический университет, specialty "Mechanical Engineering" (2009). He defended his PhD dissertation entitled "Improvement of the Manufacturing Technology of Hydraulic Machine Parts Based on the Development of Biaxial Joint Theories" supervised by Professor K.T. Sherov (Karaganda) (2014). He holds patents for 8 inventions, and has authored about 30 scientific papers and teaching notes.

D. Sh. Kossatbekova, PhD, senior lecturer. She was born in 1990 in Kazakhstan. Education: M.Kh. Dulaty Taraz State University, specialty 5B071200–"Mechanical Engineering" (2011). She defended her PhD dissertation entitled "The development and justification of the opening plow parameters of grain-sowing-grassy seeder and increase its service life of the working surface" supervised by Professor S.O. Nukeshev (Astana) (2025). She holds patents for 4 inventions, about 27 scientific papers and teaching notes.

S. O. Tussupova, Doctor of Philosophy, Postdoctoral Fellow. She was born in 1989, Kazakhstan. Education: S. Toraighyrov Pavlodar State University, degree in Standardisation, Metrology and Certification (2011). In 2020, she graduated and defended her dissertation at Karaganda State Technical University, specializing in 6D071200 – "Mechanical Engineering". Scientific supervisor: Professor K.T.Sherov, research theme: Research and development of a method for ensuring wear resistance, rigidity and strength of a thermo-friction cutting tool. In total, she has published more than 40 scientific papers.

A. Zh. Kassenov, Candidate of Engineering Sciences, Associate professor. He was born in 1980, Kazakhstan. Education: S. Toraighyrov Pavlodar State University, degree in Mechanical Engineering Technology (2002). He defended his Candidate's dissertation entitled "Development of Technology and Design of the Countersink-Broaching for Processing Cylindrical Holes" supervised by Professors T.M. Mendebayev and N.S. Dudak (Almaty) (2010). He has authored 18 patents, and 125 research papers and teaching notes.