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Satbayev University

ХАБАРЛАРЫ

ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ
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STUDY OF TEMPERATURE DISTRIBUTION DURING ROTARY TURNING OF WEAR-RESISTANT CAST IRON

Abstract. This work presents a mathematical modeling process of the rotary turning by a numerical method, which allows to research the dynamics of the temperature distribution in the workpiece and cutting tool during processing. Proposed methodology also allows to define the optimal cutting mode during the rotary turning for processing of the durable wear resistant cast iron ICH300X18G3. For performance of the study, from among the many existing models of fracture during the cutting, the criterion, which was first proposed by prof. V.L. Kolmogorov.

In order to increase the productivity of calculations, a mathematical model was proposed where only three objects were used: a cylinder-shaped workpiece and a cutting tool and tool shaft. The work considered the coefficient of friction between the cutting insert and the workpiece, taken equal to 0.29 and in addition, the dynamic coefficient of 0.39. To define the temperature in the objects, objects were separately selected. As a result, the temperature values were taken for different objects. Despite the fact that the occurring phenomena are non-linear, the results showed that by increasing the cutting conditions, it is possible to increase the distribution of temperature and on the contrary, the process is controlled. The results of the research have shown the management possibility of the thermal processes during the process by enumerating technological parameters.

Key words. Rotary turning, cutting tool, temperature, cutting zone, mathematical modeling, fracture deformation.

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ТОЗУҒА ТӨЗІМДІ ШОЙЫНДЫ РОТАЦИЯЛЫҚ ЖОНУ КЕЗІНДЕ ТЕМПЕРАТУРАНЫҢ ТАРАЛУЫН ЗЕРТТЕУ

Аннотация. Қазіргі заманғы машина жасаудың өзекті мәселелерінің бірі металдарды кесумен өңдеу үшін озық технологиялар мен прогрессивті құралдардың құрылымдарын жасау болып табылады. ЖШС «Maker» - Қарағанды құю-механикалық зауыты жағдайында жүргізілген зерттеулер, ең қиын өңделетін тозуға төзімді ИЧ300Х18Г3 шойыннан жасалған топырақты сорғы 8ГР бөлшектері екенін көрсетті.

Тозуға төзімді ИЧ300Х18Г3 шойынды ротациялық жону әдісімен өңдеу үшін Р6М5 болаттан және STOODY M7-G балқыма материалымен балқытып қапталған табақша кескіштерімен жабдықталған ротациялық құралдардың конструкциялары жасалды. Тозуға төзімді ИЧ300Х18Г3 шойынды ротациялық жону эксперименттік зерттеуі JET GH-1640ZX токарлық бұранда кескіш білдегінде жүргізілді. Әртүрлі кесу аймақтарында эксперименталды түрде температура нәтижелерін алу белгілі қиындықтарға әкеп соғады, яғни құрал-сайманның және өңделетін материалдың әрекеттесетін аймағының шағын өлшемдері, үрдістің жоғары жылдамдықта өтуі, сондай-ақ түйіспелі аймақтардың ұдайы ауысуы.

Осыған байланысты, Ansys WB бағдарламасын қолдана отырып, осы мәселені ротациялық жону үрдісін сандық моделдеу шеше алады. Зерттеуді орындау үшін кесу кезінде қираудың көптеген үлгілерінің ішінен проф. В.Л. Колмогоров ұсынған критерий қолданылды. Есептеу өнімділігін арттыру мақсатында математикалық модель ұсынылды, онда тек үш объект қолданылған: цилиндр формасындағы дайындама мен кескіш құрал және аспап білігі. Жұмыста кескіш пластина мен дайындаманың арасындағы үйкеліс коэффициентінің мәні 0,29 тең деп қабылданған және бұдан басқа динамикалық коэффициенті 0,39 есепке алынды.

Зерттеу нәтижелері технологиялық параметрлерді таңдау арқылы өңдеу кезінде жылу үрдістерін басқару мүмкіндігін көрсетті. Ұсынылған өңдеу тәсілі үшін «құрал-дайындама» түйісуіндегі температура өңделетін материалдың рекристализация температурасына жақын болу керек. Өңделетін материал үшін балқу температурасы $T_{балқ}=1200^0C$, ал рекристализация температурасы - $T_{рек} \approx 480^0C$ құрайды.

Түйін сөздер. Ротациялық жону, табақшалы кескіш, температура, кесу аймағы, математикалық модель, қирау деформациясы.

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ИССЛЕДОВАНИЕ РАСПРЕДЕЛЕНИЯ ТЕМПЕРАТУРЫ ПРИ РОТАЦИОННОМ ТОЧЕНИИ ИЗНОСОСТОЙКОГО ЧУГУНА

Аннотация. Одним из актуальных вопросов современного машиностроения является создание прогрессивных конструкций инструментов и передовых технологий для обработки металлов резанием. Проведенные исследования в условиях ТОО «Maker» – Карагандинский литейно-механический завод – показали, что самым труднообрабатываемым являются детали грунтового насоса 8ГР, изготовленные из износостойкого чугуна ИЧ300Х18Г3.

Для обработки износостойкого чугуна ИЧ300Х18Г3 были изготовлены конструкции ротационных инструментов, оснащенные чашечными резцами из стали Р6М5 и с наплавкой из наплавочного материала STOODY M7-G. Экспериментальные исследования ротационного точения были выполнены на токарно-винторезном станке JET GH-1640ZX. Получение температурных результатов экспериментально в различных зонах резания вызывает определенные сложности, вызванные малыми размерами зон взаимодействия режущего инструмента и обрабатываемого материала, большой скорости протекания процесса, а также постоянной смены контактных зон. В связи с этим, численное моделирование процесса ротационного точения может решить данную проблему посредством применения программы Ansys WB.

Для выполнения исследования из числа множества существующих моделей разрушения при резании использовался критерий, который впервые предложил проф. В.Л. Колмогоров. Для увеличения производительности вычислений была предложена математическая модель, где были использованы только три объекта: заготовка в форме цилиндра, режущий инструмент и вал инструмента. В работе учитывался коэффициент трения между режущей пластиной и заготовкой, принятой равной 0,29 и, кроме этого, коэффициент динамичности 0,39.

Результаты исследования показали возможность управления тепловыми процессами при обработке. Для этого необходимо обеспечение температуры в контакте «инструмент-заготовка», близкую к температуре рекристаллизации. Для обрабатываемого материала температура плавления составляет $T_{пл}$=1200 ^{0}C, а температура рекристаллизации - $T_{рек}$ ≈480^{0}C.

Ключевые слова: ротационное точение, чашечный резец, температура, зона резания, математическая модель, деформация разрушения.

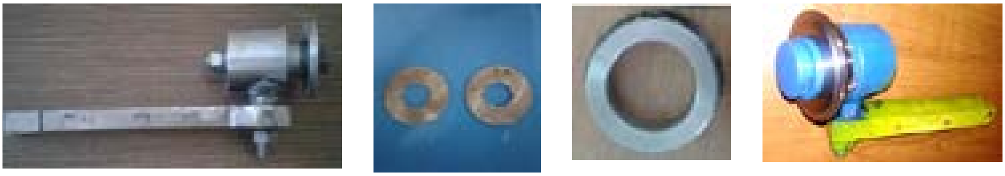
Introduction. One of the relevant issues of modern engineering is the creation of progressive tool designs and advanced technologies for metal cutting. The dominant role of mechanical processes in the technological cycle of most critical parts is due mainly to versatility, efficiency and high accuracy. At the same time, traditional mechanical processing methods that are widely used do not always satisfy the increasing demands on productivity and quality.

And also, their usage to obtain products from new materials becomes inefficient and low productive with a high consumption of expensive cutting tools. Studies conducted under the conditions of Maker LLP - Karaganda Foundry and Mechanical Plant showed that the most difficult parts of processing of the 8GR soil pump are made of wear-resistant cast iron ICH300X18G3. To process wear-resistant cast iron ICH300X18G3 by the method of rotary turning, constructions of rotary tools equipped with cup cutters were made from P6M5 steel and with surfacing from surfacing material STOODY M7-G.

Experimental studies of rotational turning of wear-resistant cast iron ICH300KH18G3 were carried out on a JET GH-1640ZX lathe. Figure 1 shows the designs of rotary tools equipped with cup cutters made of P6M5 steel and with surfacing from surfacing material STOODY M7-G.

It is known (Konovalov E.Y. et.al, 1972; Borisenko A.V. 1983), that a large reserve of increasing the productivity of the process, improving the quality of the machined surfaces is incorporated in the methods of rotational cutting, in which cup cutting tools are used as cutting elements, rotating around their axes during the cutting process.

A fundamental feature of rotational cutting lies in a sharp decrease in the sliding speeds of the working surfaces of the tool relative to the material being processed without reducing the relative speed of the tool and part by replacing the sliding friction in the contact zones with rolling friction(Konovalov E.G. et.al, 1969).



a) b)

a – rotary tool and cup cutter made of steel P6M5; b - rotary tool and cup cutter with surfacing from surfacing material STOODY M7-G

Figure 1 - Designs of rotary tools equipped with cup cutters made of P6M5 steel and with surfacing from surfacing material STOODY M7-G.

However, the poorly studied technology of rotational processing inhibits its widespread usage in production. In this regard, the study of the cutting process and in particular the temperature distribution in the contact zone of the «tool-workpiece» during rotary turning is an urgent task.

Materials and basic methods. In the mechanics of destruction, the destruction of a solid body is understood as a macroscopic violation of the integrity of the body as a result of external loads acting on It (Childs T.H. et.al, 1989) In isothermal conditions, the destruction of materials can be conditionally divided ductile fracture and brittle fracture(Shih A.J. et.al, 1991). Destruction under adiabatic conditions of deformation occurs due to localized adiabatic shear (Bobrov V.F. et.al, 1966). Viscous fracture, as a rule, is associated with large deformations, very high energy dissipation rates and low fracture rates and is intracrystalline fracture. Low fracture – as a rule is a microcrystalline fracture. It is a gap with low energy, which under loading conditions, causes instability of the process, occurs catastrophically. In this case, the rates of low fracture, as a rule, are high (Kato S. et.al, 1972). Thus, brittleness and toughness are not the structure of a material, but varieties of its state (Shirakashi T. et.al, 1973). Materials during cutting can be forced to break by viscous, brittle, and localized shear depending on temperature T, hydrostatic pressure p (negative during tension), strain rate, and other conditions in the shear zone (Otieno A. 2005). Therefore, significant hydrostatic pressures and temperatures that occur during cutting, require special approaches to the implementation of fracture models (Otieno A. 2005). From a detailed review of W. Grzesik (Otieno A. 2005), V. Astakhova (Lundblad M et.al, 2005), Yu. N. Vnukov (Childs T.H. et.al, 1990), we can see that when processing metal materials, fracture should be considered as a phenomenon due to which the material is separated in front of the cutting edge to form a new surface (cutting surface) and chip elements are formed, breaking the connection between its volumes. For example, when cutting titanium alloys, fracture by a localized shear in a thin layer, where the material has lost the ability to resist deformation, forms clearly pronounced, very offset from one another, though rather tightly interconnected chip elements (Childs T.H. et.al, 1997).

Results. Figure 2 shows an imitation of the process of rotational turning of wear-resistant cast iron ICH300H18G3. The cutting tool is a cup made of P6M5 steel.

Figure 2 – Imitation of the process of rotational turning of wear-resistant cast iron ICH300H18G3.

This methodology for studying the process is of practical interest to the distribution of temperature in the contact zone of the «cutting tool - workpiece». Obtaining temperature results experimentally in various cutting zones causes certain difficulties caused by the small size of the interaction zone of the cutting tool and the processed material, the high speed of the process, as well as the constant change of contact zones. In this regard, numerical simulation of the rotary turning process can solve this problem by using the Ansys WB program. This problem was solved earlier in other works (Togizbayeva B.B. et.al, 2020), (Sherov K.T. et.al, 2017). In these works, only two elements of the workpiece and the cutting tool were analyzed. The desire to reduce costs in developing new and optimizing existing machining processes and equipment for their implementation by virtual modeling of these processes necessitates the use of both finite- and discrete-element, as well as analytical and experimental models of cutting. However, there are still no models allowing to obtain adequate forecasts simultaneously for all indicators of the cutting process in a wide range of its parameters. This is due, first of all, to the lack of an adequate model of friction in the contact of the workpiece - the cutting wedge and, as a rule, to a rather arbitrary setting of its parameters as a constant ratio between tangential and normal stresses, called the average coefficient of friction. To build the model, the following steps were performed: a CAD model of the cutting tool and the workpiece and shaft (Geometry) was developed; input of the mechanical characteristics of the materials of the cutting tool and the shaft, the workpiece (additionally for the destructible object - Johnson Cook model) (Engineering Data) the type of contact between the surface of the cutting tool and the workpiece (Frictional) is set; decomposition into FE (Explicit) (Figure 3).

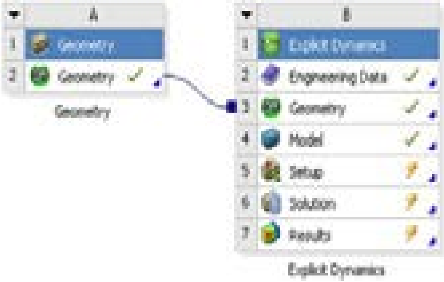


Figure 3 – Block diagram of numerical simulation.

The mechanical characteristics of cast iron, a cutting tool for a cup cutter made of P6M5 steel used in the model are presented in table 1.

Table 1 - Mechanical characteristics of cast iron

Parameters	Unit of measurement	ICH300H18G3
Density, p	kg / m^3	7000
The Young's Modulus, E	GPa	162
Poisson's ratio, ν	-	0.25
Specific heat conductivity, c_p	J/(kgK)	525
Initial temperature,T_t	°C	22
Melting temperature T_f	°C	1200

Among the various laws of material behavior under large deformations, the Johnson-Cook law is the most common. It takes into account adiabatic shear phenomena caused by the large plastic deformations and significant temperature gradients. This law establishes the dependence of the stress σ on the degree ε (%) and the strain rate, as well as on the temperature T, and can be decomposed in a multiplicative form into three functions:

$$\sigma = \left(A + B\cdot\varepsilon^{n}\right)\left(1 + C\cdot\frac{\ln\varepsilon}{\varepsilon_0}\right)\left(1 - \left[\frac{T - T_0}{T_f - T_0}\right]\right) \qquad (1)$$

The first factor describes the hardening phenomenon, the second describes dynamic processes, the third describes the vacation phenomena. The riveted multiplier corresponds to the flow stress of a constant strain rate. A is the limit of elasticity of the material under consideration, B and n are linear and nonlinear hardening parameters. The second factor is a multiplicative factor characterizing the dynamic hardening of the material. It depends on the equivalent rate of plastic deformation. C is the coefficient of sensitivity to the strain rate. We assume the initial strain rate to be 1 c $^{-1}$. The third factor is a factor corresponding to the phenomenon of thermal tempering. T_0 is the initial temperature. For temperatures between T_0 and the melting temperature T_f, the motion stress decreases along with the temperature and tends to zero at $T = T_f$. At temperatures tending to the melting temperature, the stress of motion is almost zero. Thus, T_0 is the temperature in relation to which the mechanism of thermal tempering is considered, and m is an indicator of the degree of this thermal tempering. The values of the Johnson-Cook model parameters for the workpiece materials are presented in table 2.

Table 2 - the Johnson-Cook model parameters for the workpiece

Workpieces	A, MPa	B, MPa	C	n	m
ICH300H18G3	254	639	0.26573	0.4969	1.037

The adapted failure criterion is interconnected with the Johnson-Cook law of motion. Destruction is considered for each element, starting from the moment when:

$$\omega = \sum \frac{\Delta \bar{\varepsilon}}{\Delta \bar{\varepsilon}_f} \qquad (2)$$

where $\Delta \bar{\varepsilon}$ - increment of the resulting plastic deformation,

$\Delta \bar{\varepsilon}_f$ - the resulting deformation of the material failure [18].

Destruction in the material begins when ω = 1. The Johnson-Cook fracture model takes into account thermomechanical processes at large deformations. The equation of the resulting plastic fracture deformation is presented in the form:

$$\bar{\varepsilon}_f = \left[D_1 + D_2 \cdot \exp(D_3 \cdot \sigma^*)\right] \cdot \left[1 + D_4 \cdot \ln \bar{\varepsilon}^*\right] \cdot \left[1 + D_5 \cdot T^*\right], \qquad (3)$$

where σ - the ratio of the average stress (σ_m) and the resulting von Mises stress (ε);

i - dimensionless degree of plastic deformation with ω a calculated strain rate and a limit characterizing the moment of sensitivity to the strain rate. The dimensionless temperature coefficient T^* is written in the form:

$$T^* = \left(T - T_0\right) / \left(T_f - T_0\right), \qquad (4)$$

where T_f – material melting point; T_0 – initial temperature; D_1 – initial fracture deformation; D_2 – exponential factor; D_3 – triaxiality factor; D_4 –speed deformation factor; D_5 – heat factor.

The parameters of equation (3) of plastic deformation of the destruction of the workpiece are presented in table 3.

Table 3. Parameters of plastic deformation destruction of workpieces

Workpieces	D_1	D_2	D_3	D_4	D_5
ICH300H18G3	-0,8	2,1	-0,5	0,002	0,61

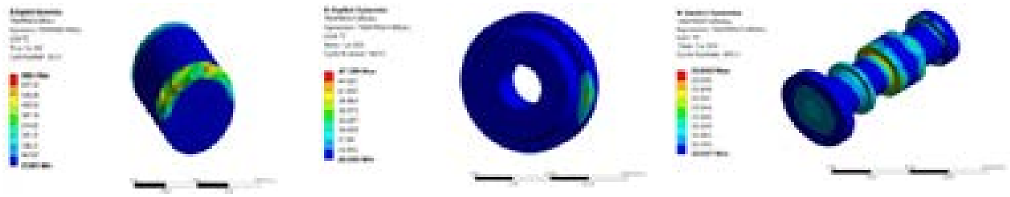
In the case when the fracture criterion is made, the criterion for the development of fracture comes into force. This criterion represents the energy level G_f necessary for the development of a crack. After a crack occurs, the behavior of the material appears to be the relationship between stress and displacement, and not between stress and deformation. For a scientific study of the cutting process, it is necessary to obtain the following information: contact force in the contact zone and temperature distribution in the workpieces (Bacaria J.L. 2001; Sherov K.T. et.al, 2018). A denser overlay of the finite element mesh allows you to get more accurate results in modeling physical processes, but it requires a lot of time. Therefore, always choose the ratio between the required accuracy and time constraints. In order to analyze the physical processes in the cutting zone, we show the surface of the workpiece in the cutting zone. Figure 4 shows the finite element mesh of the tool and the workpiece, as well as the boundary conditions.

a) b)

a - finite element mesh of the tool and the workpiece; b - boundary conditions

Figure 4 – Finite element mesh of the tool and the workpiece, boundary conditions

Discussion. According to the result obtained, it is obvious that at the same place on the contact surface the temperature of the surface layers of the workpiece and the cutting tool is different, because the same layers of the workpiece are subject to heating all the time, and since there is rotational processing, the contact surfaces of the tool are constantly updated. And as a result, the surface of the cutting cup does not heat up. Under experimental conditions, the maximum temperature on the surface of the workpiece can reach the values of heat resistance of the material, and the maximum temperature in the surface layers of the chips can reach the melting temperature of the processed material. Figure 5 shows the temperature distribution in the body of the workpiece.


a) b) c)

S = 21,6 mm/min; n = 2000 rpm; a - 40HN2MA; b - 30HGSA; c - St 45

Figure 5 - Contact temperature when processing workpieces made of various materials.

From the figures we can notice that with an increase in the number of revolutions of the workpiece (spindle), an increase in temperature is observed in the “tool-workpiece” contact. For the proposed processing method, it is necessary to ensure the temperature in the contact «tool-workpiece» close to the temperature of recrystallization of the processed material. Look at Figure 5, and when machining workpiece from wear-resistant cast iron ICH300H18G3. For the following material, the melting temperature is T_m = 1200^0, and the recrystallization temperature is T_{rec} ≈480^0. From the figure we can see that under the contact layer - this is a brightly green zone, the temperature is 460^0, and indicates that at the given processing modes the temperature in the tool-to-work contact does not exceed the recrystallization temperature. This confirms the optimality of the specified processing modes. This technique allows you to determine the optimal cutting conditions during rotary turning for processing not only this material, but also for various materials. For performing the study, from among the many existing models of fracture during cutting, we used the criterion, which was first proposed by prof. V.L. Kolmogorov. In order to increase the productivity of calculations, a mathematical model was proposed where three objects were used: a blank in the form of a cylinder, a cutting plate in the form of a cup, and a shaft of variable cross section. In addition to the coefficient of friction between the cutting insert and the workpiece, the dynamic coefficient was included in the work. A picture of the temperature distribution in the objects under study with a change in the spindle speed is obtained. The results of the study showed the possibility of controlling thermal processes during processing by sorting the technological parameters.

Conclusions. 1. The developed computer simulation model of numerical simulation of rotary turning using AnsysWB tools made it possible to study the temperature distribution in the bodies of objects.

2. This technique allows you to set the optimal cutting conditions for processing various materials, bypassing expensive costs.

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