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PARAMETERS AFFECTING THE TEMPERATURE OF THE DIAMOND CUTTING DISC WHEN CUTTING BUILDING MATERIALS

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Abstract. The cutting of natural and artificial building materials is most often carried out with metal-based diamond cutting discs at cutting speeds of the order of 50-80 m/sec. The cutting process is accompanied by considerable heat release and heating of the diamond disk. At a temperature of about 600ºC, the tensile strength of a disc is reduced by a factor of 2 and graphitization of diamond grains occurs. Thus, when cutting stone and building materials with a diamond circle, the disk heating temperature should not exceed 600°C. In the work, mathematical modeling of the heating of a diamond cutting disk on a metal base was performed while cutting ceramic materials to determine the time of continuous operation to a critical temperature of 600°C. The simulation results presented in the graphs showed the dependence of the heating temperature of the disk on the diameter of the latter, the speed of rotation, the minute feed, the grain size and the thickness of the disk.

Almost all elements of the cutting modes affect the disk temperature, although to a different extent. The vertical feed has the greatest influence. With an increase in the diameter of the cutting disk and a decrease in the rotational speed, the total cutting force, power and heating of the disk in 1 min. and increase with one revolution. The operating time to the critical temperature is significantly reduced. With an increase in the thickness of the cutting disk, the total force and cutting power increase. The simulation results showed that the grain size of the cutting disk significantly affects the important parameters of work. Therefore, if there are no special requirements for surface roughness, it is more profitable to work with a coarser-grained disk.

According to the simulation results, it can be said that in order to ensure the maximum thermal resistance of the disk, it is necessary to choose disks with a grain size of at least 25 and work at a vertical feed rate of no more than 0.05 m/min.

It is shown that by selecting appropriate process characteristics the time of continuous operation can be of the order of 10 – 12 min without the use of forced cooling.

Keywords: diamond cutting disk, disk temperature, the speed of rotation, the minute feed, the grain size, the thickness of the disk.

ПАРАМЕТРИ, ЩО ВПЛИВАЮТЬ НА ТЕМПЕРАТУРУ АЛМАЗНОГО ВІТРІЗНОГО ДИСКУ ПРИ РІЗАННІ БУДІВЕЛЬНИХ МАТЕРІАЛІВ

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Анотація. Розрізання природних та штучних будівельних матеріалів найчастіше здійснюється алмазними різальними дисками на металевій основі при швидкостях різання близько 50-80 м/с. Процес різання супроводжується значним виділенням тепла і нагріванням алмазного диска. При температурі близько 600 ºС міцність диска на розрив знижується в 2 рази і відбувається графітизація алмазних зерен. Так, при різанні каменю та інших будівельних матеріалів алмазним кругом температура нагріву диска не повинна перевищувати 600°С. У роботі проведено математичне моделювання нагріву алмазного відрізного диска на металевій основі під час різання керамічних матеріалів для визначення часу безперервної роботи до критичної температури.

Результати моделювання, представлені на графіках, показали залежність температури нагріву диска від діаметра останнього, швидкості обертання, хвилинної подачі, розміру зерна та товщини диска. Практично всі елементи режимів розрізання впливають на температуру круга, хоч і різною мірою. Найбільший вплив має величина вертикальної подачі. При збільшенні діаметра відрізного круга та зменшенні частоти обертання сумарна сила різання, потужність та нагрівання круга за 1 хв. і один оборот зростають. Час роботи до критичної температури значно знижується. При збільшенні товщини відрізного круга зростає сумарна сила та потужність різання. Результати моделювання показали, що величина зернистості відрізного круга значно впливає на важливі параметри роботи. Тому, якщо немає особливих вимог щодо шорсткості поверхні, вигідніше працювати більш крупнозернистим кругом. За результатами моделювання можна сказати, що для забезпечення максимальної теплової стійкості круга слід вибирати круги зернистості не менше 25 і працювати при швидкості вертикальної подачі не більше 0,05 м/хв.

Показано, що при підборі відповідних характеристик процесу час безперервної роботи може бути в межах 10 – 12 хвилин без застосування примусового охолодження.

Ключові слова: алмазний відрізний диск, температура диска, швидкість обертання, хвилинна подача, зернистість, товщина диска.

1 INTRODUCTION

In the process of repair and restoration of buildings, it is often necessary to cut openings and mortice where reinforcing elements are inserted. Such works are often performed in shell limestone, concrete, granite, basalt, and ceramic materials.

Currently, diamond abrasive discs are widely used for these purposes. The main advantage of diamond tools is, first of all, the possibility of obtaining high machining performance and dimensional stability, exceeding those of traditional carborundum-based tools.

The cutting of solid building materials is carried out by diamond discs with a rotation speed, which, and, consequently, the cutting speed is 35–50 m / s. Due to the high intensity of the cutting process, the cutting process is accompanied by significant heat release.

It should be noted that the disc, on which the diamond abrasive coating is applied, is made of ordinary low-alloy steel of the 9xfm steel type, (0,9% carbon and up to 1% chromium, vanadium and molybdenum). These steels have high enough tensile strength to withstand large centrifugal forces, but low heat resistance. The strength characteristics of these steels when heated to temperatures of 500 – 600ºC decrease by almost 2 times, which can cause jamming or even breakage and rupture of the tool during operation.

In addition, the graphitization of diamond cutting grains, i.e. the transformation of tetragonal carbon into hexagonal also occurs at a temperature of about 600ºC, which can lead to the loss of the diamond-bearing layer.

Thus, when cutting stone and building materials with a diamond disk, the heating temperature of the wheel should not exceed 600ºC. Therefore, the working time of a diamond cutting disk is the time during which it heats up during continuous operation to a temperature of 600ºC. The longer this time, the higher the efficiency of the diamond disk.

At present, there is no database on the appointment of cutting modes with synthetic diamond disks, which would determine the patterns of heating and cooling of the diamond cutting wheel during operation.

There is no methodology for determining the operating time up to the critical temperature and the issues of increasing the operating time resource up to the critical temperature have not been considered.

Diamond disk are produced in various sizes and different grain sizes, so the experimental study of this issue is very laborious and lengthy. In addition, there is no reliable technique that would allow these measurements to be made.

2 LITERATURE REVIEW

Despite the large amount of literature on cutting stone and ceramic materials with diamond disks, there is practically no information about the parameters of the cutting process that allow you to control the temperature of the disc during operation. This does not make it possible to develop an optimal cutting technology, determine the time of the disc to the critical heating temperature, and also does not make it possible to develop an effective method for cooling the disc.

A large number of works are devoted to the energy of the cutting process, the wear of cutting discs and ways to maintain the energy characteristics of the process in certain parameters.

In [1], the author considers in detail the process of cutting natural stones with a diamond disk tool. The author very skillfully determines the characteristics of diamond grains, the number of actually cutting grains in the contact spot of the disk with the product. On this basis, the author determines the individual and total cutting forces. However, there are no thermal calculations either in relation to the workpiece, or in relation to the heating of the diamond disk on a metal base.

In [2], general issues of progress in abrasive processing are considered, but there are no data on the heating temperature of diamond wheels on a metal bond.

In [3], the issues of wear of a diamond cutting disk are considered, depending on the content of boron carbides in the diamond-bearing layer. The issues of heating the disk during processing are not considered.

In [4], the author uses electrical, chemical and optimal energy sources to bind, form and cut materials in the processing of hard-to-cut materials. The author explains in detail how each of these advanced processes works. Thermal issues are not affected.

The work [5] explores issues – energy nature – the dependence of cutting forces and cutting power on specific conditions and processing modes. However, the issue of energy costs for heating the circle is not considered.

In [6], the wear of diamond sectors is considered. Using mathematical methods, the authors predict disk wear depending on the amount of chips removed. Thermal effects are not considered in the work.

In [7, 8] considers the energy characteristics of the process. Cutting forces and power are associated with the amount of chips removed, which can make it possible to reasonably assign cutting modes.

In [9], the influence of the disk periphery speed on wear is considered. These studies also make it possible to prescribe the mode of cutting more reasonably. Thermal issues are not considered.

In [10], the issue of automatic control of the saw speed and feed per tooth is considered, which makes it possible to increase the efficiency of the cutting process. Thermal issues are also not considered and, in addition, the results of the study of the cutting process with a circular saw cannot be fully transferred to the cutting process with a disc.

In [11], the dependences of the specific energy of cutting and the specific energy of drilling. Thermal issues are not affected.

In [12], the issues of wear of a diamond cutter by measuring the cutting force are considered. Despite the thoroughness of the experiment carried out on modern equipment, the results cannot be applied to the topic of this work.

It can be concluded that at present there is no data in the literature on the heating of a diamond disk on a metal base during operation.

3 PURPOSE AND OBJECTIVES OF THE RESEARCH

In the present work, mathematical modeling has been carried out, which makes it possible to determine the safe operation time up to the critical temperature. In addition, some ways of increasing the time resource are modeled. Thus, it is possible to create a database of preferred operating modes and experimentally refine the mathematical model pointwise.

To achieve the goal of the work, it is necessary to solve the following tasks:

1. Determine the cutting forces of a single grain during the cutting process.

2. Determine the thermal power developed by a single grain when cutting a building material.

3. Determine the shape of the contact spot of the wheel with the product, determine the number of grains acting in the contact spot and the value of the total heat flux during cutting.

5. Develop a block diagram and a calculation program (in the MathCad environment), which makes it possible to determine the total cutting forces, the contact temperature of the cut, and the circuit for heating the disk with this temperature.

6. Based on the data obtained, determine the heating temperature of the section of the circle in contact with the product, the temperature along the radius of the circle, the cooling of

the heated circle by the air flow and the increase in the temperature of the disc for each revolution.

4 RESEARCH RESULTS

The studies were carried out using mathematical modeling and direct experiments. The material used is tiles and briquettes made of zirconium oxide.

The amount of grain deepening into the material:

$$P_Z = 7{,}15 \times H_V \times h^2,$$

where H_V is the hardness of the material being cut on the Vickers scale, h – the average depth of the grain in the material. The multiplication $P_Z V_d$ (disc speed) gives the value of the thermal power of cutting by a single grain. To determine the last value, the technique described in [13] was used. Thermal pulse from a microthermocouple makes it possible to determine: the number of actual cutting grains in the arc of contact between the disc and the product, the distance between the cutting grains, and the specific number of cutting grains. By measuring the actual cut of the material in each pass and dividing this cut by the number of grains, it is possible to determine the average depth of grain penetration into the material being ground or cut.

If we dwell on the example of cutting a ZrO_2 briquette with vertical feed, as shown in Fig. 1, then the following notation can be introduced.

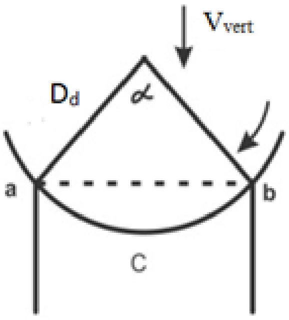

Fig. 1. Scheme of cutting a ZrO_2 ceramic sample with a diamond cutting disc on a metal base.
D_d - disc diameter, V_d - disc speed, V_{vert} - vertical feed speed, n - rotation frequency

The chord of the sector of the part of the circle currently within the sample, ab=C. α – sector angle, L_{cont} – length of the contact arc equal to $L_{cont} = 2arcsin\left(C/D_d\right) \cdot R$.

For an approximate calculation, we determine the contact area of the cutting edge of the disc with the product. It will obviously be equal to $F_{cont} = L_{cont} \times S$ and, when projected onto a plane, will be an elongated rectangle. If we take the time interval from point a to point b, then the time of thermal exposure from point a to point b can be considered as a short period of time equal to $\tau = L_{cont}/V_d$. Thus, we reduce the problem to an instantaneous flat source. The errors arising from the use of this model can be determined in the future with experimental measurements.

The atmosphere in which the cutting disc operates consists of a boundary layer of air that exists around the disc, regardless of its structure and porosity. [14]. This, in turn, means that when cutting, the air intensively blows over the disc and a significant decrease in temperature can be expected, especially since heat is released within one revolution of the disc from most of its surface. To determine the amount of heat carried away from the surface of the disc, we determine the heat transfer coefficient for these conditions.

To estimate this amount, it is necessary to find the coefficient of convective heat transfer between the moving medium and the blown surface (wall).

The amount of heat transferred in the process of heat transfer is determined by the Newton-Richmann equation:

$$Q = \alpha\left(t_w - t_l\right)F,$$

where α – is the heat transfer coefficient, W/(m^2·K); t_w, t_l – are the average temperatures of the liquid and the wall, °C; F – is the wall surface, m^2; Q – is the heat flux (amount of heat), W(J); τ – is time, sec.

Heat transfer coefficient α – characterizes the intensity of heat transfer between the surface of the body and the environment. The coefficient α shows how much heat is transferred from a unit of the wall surface to the liquid per unit time with a temperature difference between the wall and the liquid of 1 degree (K),

$$[\alpha] = \left[\frac{Q}{F\left(t_w - t_l\right)}\right] = \left[\frac{J}{m^2 \times sec \times K}\right] = \left[\frac{W}{m^2 \times K}\right].$$

Determining α is the main task of calculating heat exchangers. The easiest way to determine the heat transfer coefficient is through the Nusselt criterion using the expressions:

$$\alpha = \frac{Nu \times \lambda}{l} \tag{1}$$

and

$$Nu = 0.008Re^{0{,}9} \times Pr^{0{,}43},$$

where

$$Re = \frac{\omega l}{v} = \frac{\overline{\omega} lp}{\mu}$$

the Reynolds criterion, which characterizes the hydrodynamic flow regime during forced motion and is a measure of the ratio of inertia forces and viscous friction;

$$Pr = \frac{v}{\alpha} = \frac{c\mu}{\lambda}$$

the Prandtl criterion, which characterizes the physicochemical properties of the coolant and is a measure of the similarity of temperature and velocity fields in the flow;

where – l is the defining size, m; ρ – is the heat carrier density, kg/m^3; $\Delta t - t_w - t_l$ – temperature difference between the wall and the coolant, °C; λ – is the thermal conductivity coefficient of the coolant, W/(m·K); μ – is the dynamic coefficient of viscosity, Pa·sec; c – is the heat capacity of the coolant, J/(kg·K); τ – is the process time, sec, ω – is the speed of the coolant, m/sec.

The calculation of the Nu criterion for an air flow velocity of 30 - 50 m/sec and for an air temperature of $20^\circ\mathrm{C} = 293^\circ\mathrm{K}$, according to the above formulas (1), is 51,34. Accordingly, the heat transfer coefficient α will be, according to formula 1, $\alpha = 445\,\mathrm{W/m^2\ ^\circ K}$.

In order to determine the amount of heat carried away from the surface of the contact spot of the disc with the product, it is necessary to multiply the length of the arc of the contact of the disc with the product and the value of the transverse feed.

The calculations were carried out by changing the parameters in the MathCad program and are shown in Fig. 2.

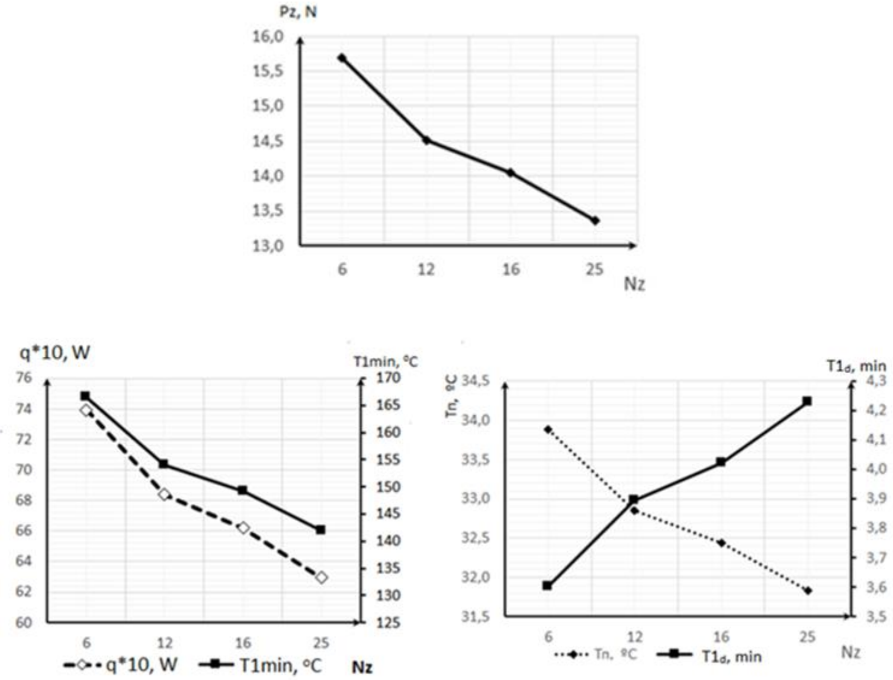

Fig. 2. Dependence of the cutting parameters on the change in the grain size of the disc

The simulation results showed that the grain size of the cutting disc significantly affects the important parameters of work. The total cutting force decreases despite the fact that the unit cutting force increases. This is explained by the fact that with an increase in grain size, the number of simultaneously working grains sharply decreases. Therefore, if there are no special requirements for surface roughness, it is more profitable to work with a coarser-grained disc, despite its higher cost. According to the change in the total cutting force, the laws of change in the cutting power and the heating temperature of the disc for 1 minute of work follow the same pattern. The temperature of the disc for one revolution slowly decreases, but quite naturally, the operating time increases to the critical temperature (Fig. 3).

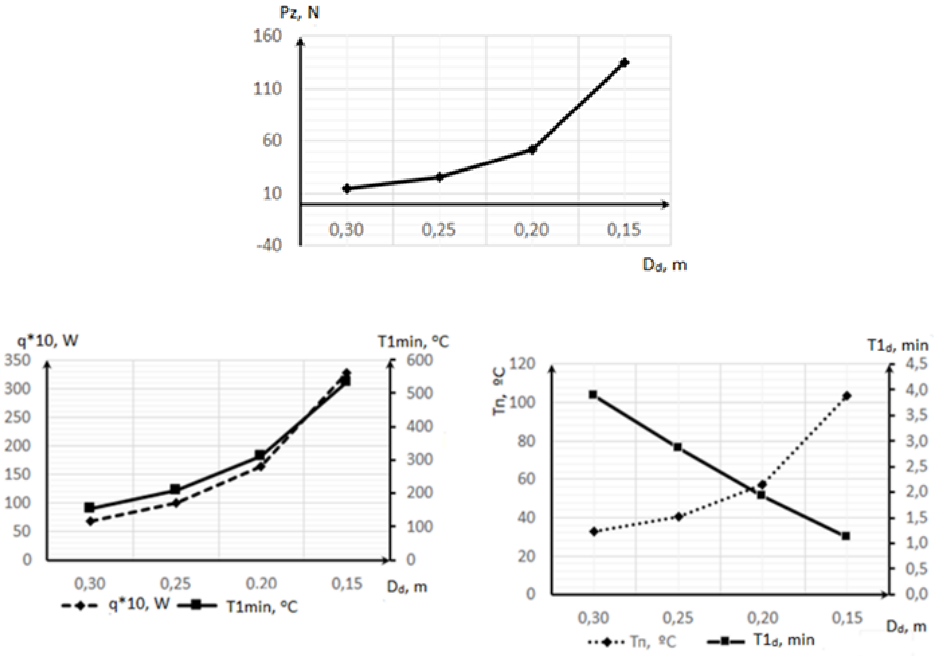

Fig. 3. Dependence of the cutting parameters on the change in the diameter of the cutting disc

The total cutting force, power and heating of the disc for 1 min. increase. The heating temperature of the disc for 1 revolution increases. The operating time to the critical temperature is significantly reduced (Fig. 4).

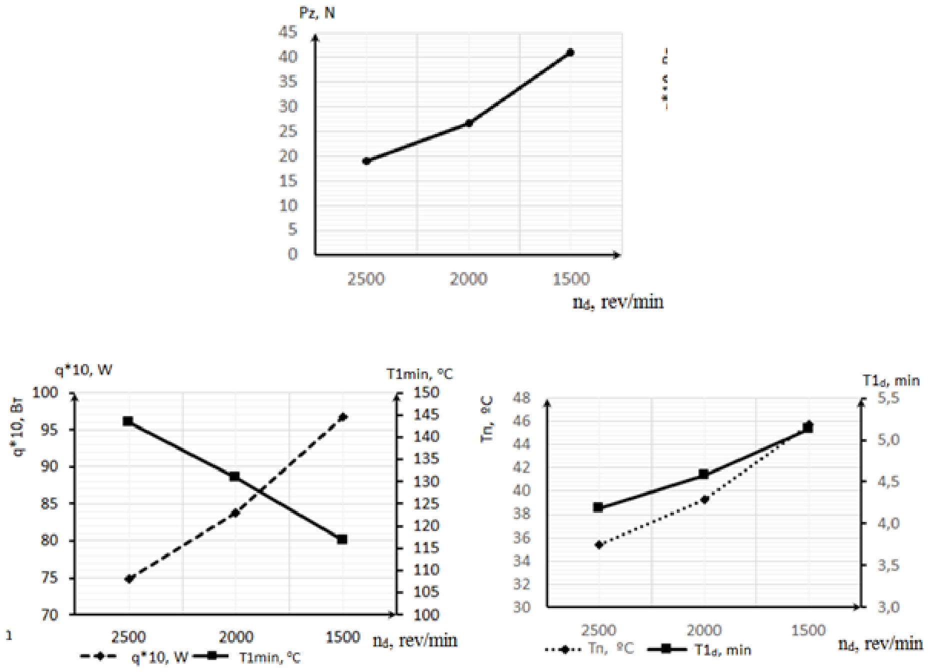

Fig 4. Dependence of the cutting parameters on the change in the rotational speed of the cutting disc

Reducing the rotational speed causes an increase in the total cutting force, cutting power, heating temperature of the disc for 1 revolution. The operating time to the critical temperature increases significantly (Fig. 5).

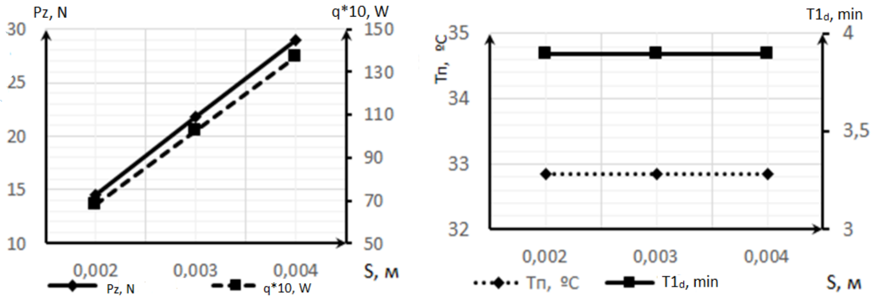

Fig 5. Dependence of the cutting parameters on the change in the rotational speed of the cutting disc

With an increase in the thickness of the cutting disc, as expected, the total force Pz and cutting power increase. All other parameters remain unchanged. The reason for this is that the intensity of the heat flux remains unchanged (Fig. 6).

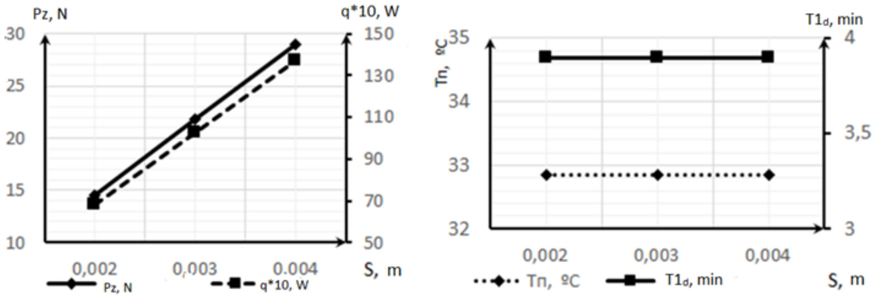

Fig. 6. Dependence of the cutting parameters on the change in the rotational speed of the cutting disc

With an increase in vertical feed, the total cutting force increases. The load on the cutting grain increases by increasing the average value of the penetration of the grain into the material. The cutting power and the heating temperature of the wheel increase in 1 minute. The heating of the disc for 1 revolution also increases. The operating time to the critical temperature is significantly reduced.

5 DISCUSSION OF RESEARCH RESULTS

Mathematical modeling has shown that the metal disk - the basis of the diamond wheel, heats up significantly during operation.

Almost all elements of the cutting modes affect the disc temperature, although to a different extent. The vertical feed has the greatest influence.

The speed of the disc and the change in its diameter have almost the same effect, since the cutting speed depends on both the speed and the diameter of the disc.

Changing the grain size of the cutting disc significantly affects its heating. The dependence here is quite complex, since an increase in the grain size increases the unit cutting force and thermal power from each individual grain. However, this reduces the number of grains simultaneously involved in the work. In our case, a smaller number of more powerful heat sources take part in heat generation. However, an increase in the power of each single source cannot compensate for a decrease in their number. This phenomenon must be checked on other discs, for example on a ceramic bond.

According to the simulation results, it can be said that in order to ensure the maximum thermal resistance of the disc, it is necessary to choose discs with a grain size of at least 25 and work at a vertical feed rate of no more than 0.05 m/min.

6 CONCLUSIONS

As a result of the mathematical modeling, the following issues were resolved:

1. The cutting force of a single grain during the cutting process is determined.

2. The thermal power developed by a single grain when cutting a ceramic material is determined.

3. The shape of the contact spot of the disc with the product is determined, the number of grains acting in the contact patch and the value of the total heat flux during cutting are determined.

5. A calculation program has been developed (in the MathCad environment), which makes it possible to determine the total cutting forces, the contact temperature of the cut, and the scheme for heating the disc with this temperature.

6. Based on the data obtained, the heating temperature of the section of the circle in contact with the product, the temperature along the radius of the circle, the cooling of the heated disc by the air flow and the increase in the temperature of the circle for each revolution were determined.

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