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Use of disc working body machines for cutting high-strength building materials in production and construction site environments

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Abstract. At the present stage of development of the processing of solid materials, the science of cutting materials is intensively developing in such cardinal directions as the search for new effective tool materials; in-depth study of cutting physics; improving the quality of the formed surfaces along with the need to intensify operating modes, in particular, cutting speed; creation of new effective lubricating and cooling media; research and systematization of the experience of machinability of the latest structural materials – high-strength and heat-resistant steels and alloys, synthetic materials with various properties, refractory materials, graphite and carbon fibers, parts made of hard alloys of all grades, fiberglass-reinforced plastics, various semiconductor materials of finishing materials and products made of natural stone; development of technical standards for all known types of cutting processing; Optimization of cutting operations on automated equipment, in particular on CNC machines and in flexible automated production environments.

Cutting natural and artificial stone materials is an operation, in the process of which a wide range of materials with different physical and mechanical properties is to be processed.

Keywords: abrasive reinforced wheels, cutting, high-abrasive materials, temperature, connection, lateral surfaces.

INTRODUCTION

The widespread use of machines for cutting high-strength materials in the construction industry is due to their efficiency in performing finishing operations, various technological processes [3]. A special place belongs to machines for cutting high-strength materials during the processing of materials from natural and artificial stones at construction sites, during the construction of road surfaces, bridges, crossings [5]. At the present stage of development of cutting processes for high-strength materials, increased requirements are put forward for the need to reduce energy consumption, reduce the cost of working tools, and increase the efficiency of using disc working bodies.

The main goal defined by this area of research is to substantiate the modes and parameters of the working body of the machine with the processed material, which subsequently formed a number of tasks that must be solved to achieve the set goals, one of which is to inspect and analyze machines with a working body for cutting high-strength building materials.

PRESENTING MAIN MATERIAL

Various machines and devices are used to cut and process high-strength materials, which also include artificial and natural stone. Fig. 1. a) shows an electric machine for cutting seams [11].

a

b

Fig.1. Electric seam cutting machine: a - CF33E; b - CF-4100

The CF33E electric machine is manufactured by CEDIMA (Germany) and is used to form seams up to 270 mm deep. The maximum diameter of the disc is 700 mm, the engine power is 7.5 kW, the weight of the machine is 110 kg. A slightly different design of the CF-4100 seam cutting machine of the same CEDIMA company is shown in Fig. 1b). This machine is used for cutting and cutting joints in asphalt and concrete, in the construction and repair of highways, streets, runways and industrial structures. The machine is equipped with high-performance hydraulic equipment. The inclusion of the drive for the rotation of the cutting shaft, as well as the tension of the V-belts, is carried out by a hydraulic drive. Steering (Control), hydraulic feeding, hydraulic disc recess, hydraulic tension of the V-belt of the cutting shaft and additional hydraulic recess of the sight provide ease of operation of the machine. The depth of cut indicator is easily and quickly adjustable. The presence of a seat and a well-located control panel provide comfortable conditions for the operator. The technical characteristics of the machine are shown in Table 1.

Table 1. Technical characteristics of the CF-4100 machine

№ p/p	Parameter name	Dimension	Numerical value
1	Cutting disc, diameter	Mm	1000
2	Depth of Cut	Mm	350
3	Maximum number of disk revolutions	rpm	1470
4	Performance	m/min	53
5	Mass	Kg	1150
6	Engine power	Kw	60

The DS TS20-E machine, shown in Fig. 2, is designed for cutting material in the construction of highways [12].

a

b

Fig. 2. Cutting machine for the construction of highways: *a* - appearance; *b* – concrete cutting process

The DS TS20-E is designed for cutting various categories of reinforced concrete – from light to heavy, brickwork and natural stone using diamond cutting discs with a diameter of 600, 800, 900, 1000, 1200 or 1600 mm (the maximum diameter of the cutting disc for initial cutting is 800 mm). All working functions of the machine are controlled by a remote control. The speed of rotation of the cutting disc can be controlled smoothly and without jumps over a wide range. The cutting disc drive provides a constant power output. The feed of the cutting head is controlled manually or automatically. The system operates in fully automatic mode at the maximum power set on the control panel. The productivity of the machine will be maximized in the event that the cutting head of the DS TS20-E machine is used by Hilti DS-B wall cutting discs [12]. Diamond cutting discs that comply with the EN 13236 standard have been found to be suitable for cutting with a linear cutting speed of at least 63 m/s. In the case of cutting discs with a diameter of 1200 to 1600 mm, only those wall-cutting discs that are suitable for operation with a linear cutting speed of at least 80 m/s are used.

Table 2. Technical characteristics of the DS TS20-E machine

№ p/p	Parameter name	Dimension	Numerical value
1	Cutting disc, diameter	Mm	600-1600
2	Depth of Cut	Mm	730
3	Amplitude-weighted sound pressure level	dB(A)	100
4	Drive weight	Kg	37
5	Engine power	Kw	15

The manual hard material cutting machine (Fig. 3) is used for cutting concrete blocks, natural and artificial stone.

Fig. 3. Manual machine for cutting hard materials

The machine is suitable for both dry and wet cutting depending on the working material. The technical characteristics of the machine are given in Table 3 [14].

Table 3. Technical Specification of Zipper ZI-BTS350 Machine

№ p/p	Parameter name	Dimension	Numerical value
1	Cutting disc, diameter	Mm	350
2	Depth of Cut	Mm	115
3	Maximum number of disk revolutions	rpm	4850
4	Mass	Kg	12
5	Engine power	Kw	3.3

Disc rock machine YS-05SS Yichen - China (Fig. 4) has a simple structure, can be installed directly on an excavator, is used for cutting reinforced concrete and various hard stones such as granite, basalt, marble [15].

Fig. 4. Yichen Hard Material Cutting Machine YS-05SS

The working body is a durable disc that is made of high-quality spring steel and synthetic diamond. The machine has a fast automatic braking function, a two-directional operation function, is equipped with a protective cover and can rotate 360° if necessary. The rock saw can work with any hydraulically driven mechanical equipment. Two saw blades can be installed on the machine at the same time (on one side), the distance between the blades is 50-200 mm. The technical characteristics of the machine are shown in Table 4.

Table 4. Technical Characteristics of YS-05SS Yichen Machine

№ p/p	Parameter name	Dime-nsion	Numeri-cal value
1	Cutting disc, diameter	Mm	800-1400
2	Output torque	Nm	600
3	Number of revolutions of the output shaft	rpm	0-600
4	Mass	Kg	250
5	Maximum engine power output	Kw	41

Shijing 9510 Electric Automatic Large Format Tile Cutting Machine – China (Fig. 5) is used to cut any type of ceramic tile, natural and artificial stone, such as porcelain stoneware, marble, quartz agglomerate.

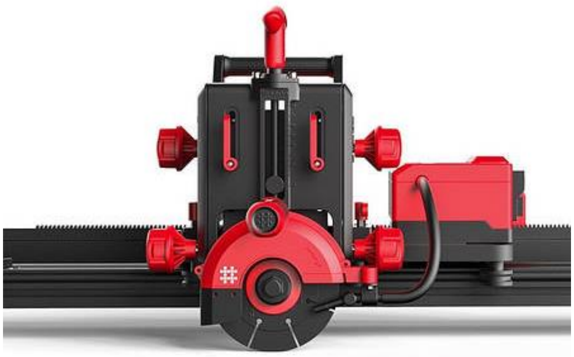

Fig. 5. Shijing 9510 Electric Automatic Large Format Tile Cutting Machine

The machine is equipped with a powerful and high-speed motor, which makes it possible to perform two operations in one pass: cutting and edge processing with a chamfered disc. The technical characteristics of the Shijing 9510 machine are given in Table 5 [16].

Table 5. Technical Specification of Shijing 9510 Machine

№ p/p	Parameter name	Dime-nsion	Numeri-cal value
1	Cutting disc, diameter	Mm	115, 120 and 125
2	Cutting length	Mm	3200
3	Cutting thickness	Mm	35
4	Motor shaft speed	rpm	13000
5	Mass	Kg	250
6	Engine power	Kw	2.8

The Husqvarna WS 482 HF machine for cutting concrete in the wall, as well as bricks and other building materials, is shown in Fig. 6.

Fig. 6. Husqvarna WS 482 HF machine for cutting durable materials

The electric motor of the machine is water-cooled, creates power on the spindle of 19 kW at a current of 32 A or 9 kW at a current of 16 A [13]. The two-speed gearbox provides operation in a wide range of revolutions and allows the use of discs with a diameter of up to 1600 mm. The spindle speed is infinitely adjustable

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using the remote control to optimize performance under all application conditions. The direction of rotation of the disc can also be changed using the remote control to ensure the desired direction of dust and sludge removal. Since the rails and carriage are symmetrical, it is possible to cut on both sides of the rail. The modular design of the wall cutter makes it easy to transport and store. The remote control provides the operator with a variety of information (power level, current pressure, operating time, maintenance periods, etc.), which allows full control of the cutting process with considerable freedom of movement on the jobsite. The weight is also evenly distributed between the rail and the head because the cart is on the rail. The rotation of the disc makes it possible to choose the direction of rotation of the cutting disc and the water supply in the desired direction. The operator can also adjust the speed and power of the machine based on the diameter of the cutting disc, the type of disc and the material being cut. Wall cutting machines WS 440 and WS 482 have an ideal ratio of machine power to weight. A water-cooled two-speed gearbox that provides a wide range of rotational speeds, suitable for discs up to 1600mm in diameter. Thanks to this, the WS 482 HF carver can be used for a wide variety of jobs. A specially designed flange with 6 mounting holes allows you to cut close to the wall. The technical characteristics of the machine are given in Table 6 [13].

To generalize the technical characteristics of the above machines for cutting high-strength materials and to compare technological parameters, their evaluation was carried out.

Table 6. Technical characteristics of the Husqvarna WS 482 HF machine

№ p/p	Parameter name	Dimension	Numerical value
1	Cutting disc, diameter	Mm	up to 1600
2	Depth of Cut	Mm	up to 730
3	Mass	Kg	25
4	Engine power	Kw	16-19

The numerical values of the parameters of the studied machines are given in Table 7.

Evaluation and comparison of technological parameters of material cutting machines was carried out according to the following criteria:

$$K_1 = \frac{П}{m}, \qquad (1)$$

where K_1 is the criterion for evaluating the effect of mass m on productivity P;

$$К_2 = \frac{h}{Р}, \qquad (2)$$

where K_2 is the criterion for the influence of energy expenditure P on the cutting depth h;

Table 7. Technical characteristics of machines

Type machinery	Performance P, m/min	Table m, kg	Tension P, kW	Technological parameters		
				RPM	Cutting depth, mm	Diameter disk, mm
CF33E	-	110	7.5	-	270	600
CF-4100	53	1150	60	1470	350	1000
DS TS20-E	-	37	15	100–940	730	600 -600
ZI-BTS350	-	12	3,3	4850	115	350
YS-05SS	-	250	41	0-600	-	800-400
Shijing 9510	-	250	2,8	13000	35	115-125
WS 482 HF	-	25	16-19	1000	up to 730	1600

$$K_3 = \frac{P}{m}, \qquad (3)$$

where K_3 is the criterion for the influence of power P on mass m;

The calculated criteria of the studied cutting machines are given in Table 8.

Table 8. Numerical values of the criteria of the studied machines

Type machinery	K1	K2	K3
CF33E	-	36	0,068
CF-4100	0,48	5,83	0,052
DS TS20-E	-	48,70	0,405
ZI-BTS350	-	34,85	0,275
YS-05SS	-	-	0,164
Shijing 9510	-	12,5	0,011
WS 482 HF	-	45,6-38,4	0,64-0,76

In existing machines for cutting high-strength materials, diamond circular saws are mostly used as a working body [4]. The complexity and specificity of the problem of introducing tools with a working part made of synthetic diamonds or other abrasive components for processing building materials is:

- organization of production of large volumes of abrasive materials with a wide range of grains and properties;
- the need to meet special requirements for rolled metal used in the structures of this class of tools;
- the need to develop many different special connections;
- the emergence of questions regarding the technologies of sintering abrasive composites;
- the need to straighten housings, solder segments, balancing,
- the need for strict adherence to operating technologies;
- organization of development and adjustment of industrial production of relevant equipment.

Assessment of the performance of abrasive tools among consumers is carried out according to the following parameters:

- cutting properties of the tool - removal of material per unit of time;
- tool consumption – wear per unit of time;
- processing coefficient – the ratio of the mass of the removed material to the mass of the used tool;
- roughness of the treated surface;
- stability of the tool between edits.

Sometimes various production indicators are determined that expand the values of these main ones.

The performance of an abrasive tool is simultaneously influenced by a large number of technological factors and their combinations that arise both in the process of its manufacture and during its operation [1].

All these factors are divided into two groups.

The first group includes:

– deviations in geometric parameters (within the limits of regulated standards): tolerance for the diameter of the circle, the diameter of the seat, the height of the circle, the parallelism of the end surfaces and the eccentricity of the axis of the hole or tucks;

- the degree of imbalance caused by the unevenness of hardness and the presence of deviations in geometric parameters;
- tool working speed;
- abrasive material;
- Grain;
- structure;
- Bunch;
- recipe and a number of others.

The second group includes:

- material of the surface to be treated;
- surface condition;
- shape and size of the surface;
- tool size;
- processing method;
- design and condition of equipment;
- processing mode;
- cooling method and type of lubricating and cooling fluid, etc.

Such a large number of factors makes it almost impossible to determine the impact of each of them on the operational indicators of the entire operation with existing measuring (control) tools.

The variety of materials used in modern construction and their composites with different physical and mechanical properties necessitates the creation of appropriate tools that can ensure the processing of these materials with the maximum possible technical and economic indicators.

Correctly selected characteristics of abrasive tools and the material from which they are made decisively affect this [6].

Also, the processing mode affects the performance of the process.

Abrasive reinforced wheels during operation experience a complex stress state resulting from the action of centrifugal, bending, tangential forces and normal forces [2].

When rotating in a circle, centripetal accelerations occur:

$$a_ц = \frac{V_p^2}{R_o}, \qquad (4)$$

where V_p is the speed of rotation of the circle; R_o is the radius of the circle

The existing centripetal accelerations lead to the appearance of centrifugal forces that directly affect the occurrence of tensile stresses on the inner circuit of the circle, comparable in magnitude to the tensile strength of its material [7].

Bending forces constantly act on the cleaning wheels, and can also appear in the cutting wheels when they are skewed or clamped.

For a cleaning wheel, bending loads can be represented by a concentrated force *Fzg* (Fig. 7) applied to the cutting edge and an equal force Pv, with which the operator presses the wheel against the surface to be treated, multiplied by the sine of its inclination angle α.

Stresses caused by bending forces can also reach values comparable to the tensile strength of the material of the circle on the inner circuit.

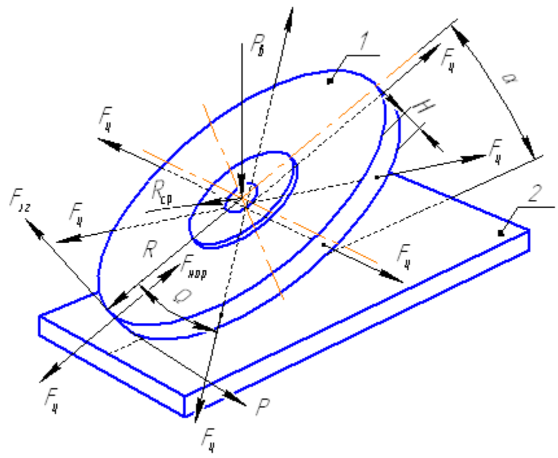

Fig. 7. Diagram of forces acting on a circle: 1 – circle; 2 – object of processing

Tangential forces are due to the friction of the cutting edge of the disc against the cutting material and are directed in the opposite direction to the centrifugal ones.

Even in the danger zone, the tangential stresses of the clamping flange are much lower than the maximum permissible for the wheel material and may not be taken into account.

Tangential force occurs when the wheel stops due to jamming or sudden acceleration. It is associated with the presence of inertia in the tool and is proportional to the density of the circle and the acceleration of angular braking or acceleration. In practice, this force does not reach large values and can also be ignored due to the fact that all circles are tested at rotation speeds 1.3÷1.5 times higher than the working ones, and when braking, the tangential force is directed in the opposite direction to the force caused by the friction of the cutting disc against the material.

Normal forces act when working with stripping and cutting wheels and lead to compression of the wheel. Since the cause of the fracture of a brittle material is usually tensile stress, normal forces can be ignored.

The design of the abrasive reinforced wheel significantly affects its strength indicators.

Thus, it was found that the abrasive reinforced wheel is an anisotropic body, while the orthotropy of its mechanical properties is observed [10]. To determine the stress that occurs in a circle under the action of centrifugal forces, the dependencies used in the theory of elasticity to calculate orthotropic bodies can be used:

$$\sigma_{\text{r}} = \frac{\text{E}}{1-\mu^2} \cdot (\varepsilon_r + \mu \cdot \varepsilon_\theta), \qquad (5)$$

$$\sigma_\theta = \frac{\text{E}}{1-\mu^2} \cdot (\varepsilon_\theta + \mu \cdot \varepsilon_r), \qquad (6)$$

where is the radial stress;σ_{r}

σ_θ – tangential stress;

$E = 3 \cdot 10$ kgf/cm^2 is the modulus of elasticity of the wheel material in the direction of the fibers of the fiberglass mesh;

$\mu = 0.2$ – Poisson's ratio;

εr – deformations in the radial direction;

$\varepsilon\theta$ – deformations in the tangential direction.

The use of these dependencies is complicated due to the need to determine the value of the modulus of elasticity and deformations dependent on the physical and mechanical properties of the bond and fiberglass mesh, its design and tool operating modes in each specific case[8].

Therefore, for practical purposes, the maximum tangential and radial stress can be calculated taking into account the influence of anisotropy according to the formulas used to determine the stress in an isotropic disk:

$$\sigma_{\text{r}} = \frac{k \cdot \gamma \cdot \omega^2}{8} \cdot (3+\mu) \cdot \left(R^2 + r^2 - -\frac{R^2+r^2}{R_1^2} - R_1^2\right), \qquad (7)$$

$$\sigma_\theta = \frac{k \cdot \gamma \cdot \omega^2}{8} \cdot (3+\mu) \cdot \left(R^2 + r^2 - -\frac{R^2+r^2}{R_1^2} - \frac{1+3\gamma}{3+\gamma} \cdot r^2\right), \qquad (8)$$

where k is the coefficient that takes into account the anisotropy;

γ – 2.5·103 – density of the wheel material, kg/m^3;

ω is the angular velocity, rad/s;

R is the outer radius of the circle, m;

r is the radius of the landing hole, m;

$R1$ is the distance from the center of the disc to the point at which the voltage is determined, m.

When studying the stress arising from bending forces, it was taken into account that the wheel is rigidly fixed and the maximum bending moment acts on the outer radius of the flange.

According to the beam theory, the maximum stress is calculated by the formula:

$$\sigma_{\max} = \frac{3 \cdot F_{3\text{r}} \cdot (R - R_2)}{h^2 \cdot \sqrt{R^2 - R_2^2}}, \qquad (9)$$

where F is the bending load acting on the circle, H;

R is the outer radius of the circle, m;

$R2$ is the radius of the clamping flange, m;

h is the height of the circle, m.

The amount of bending forces depends on many factors, in particular on the cutting depth, the rigidity of the spindle assembly of the drive mechanism and can be obtained experimentally [9].

CONCLUSIONS

According to the above dependencies, it is possible to determine the limit values of the forces acting on the abrasive reinforced wheel, taking into account its purpose and operating conditions.

These values should not exceed the tensile and tensile strength. For cutting wheels, the effect of centrifugal forces should be taken into account.

The efficiency of processing depends on the modes and methods of cutting, the composition and design of the wheel, as well as the geometric dimensions of the tool, the configuration and physical and mechanical properties of the product to be processed.

The wear resistance of the tool and the cutting performance, all other things being equal, are mainly determined by the working speed, feed speed and arc length of the contact of the wheel with the material.

Inspection and analysis shows the coverage of significant application of this class of machines from cutting grooves in structures and walls to cutting light and heavy reinforced concrete, in the construction and repair of roads, laying natural stone using cutting wheels of various diameters: 600, 800, 900, 1000, 1200 or 1600 mm.

There are a number of different design solutions for machines for cutting and processing

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materials, which also include artificial and natural stone. The main design difference lies in the purpose and methods of controlling the operation of machines.

The calculated criteria for the efficiency of the parameters, the numerical values of which are given in Table 1.8, indicate a significant discrepancy with each other (for example, such an important criterion as the influence of energy expenditure on the cutting depth h ranges from 5.83 to 48.70). Obviously, this is evidence of a different approach to the design of working bodies and the machine as a whole and the lack of a generally accepted model of the cutting workflow.

Assessment of the performance indicators of the working bodies of machines for cutting and processing artificial and natural stone showed the presence of a large number of technological factors and their combinations that arise both in the process of their manufacture and during operation. This is due to the fact that abrasive reinforced wheels in the process of operation are in a complex stress state, which occurs as a result of the action of normal, centrifugal, bending, and tangential forces.

The analysis of existing analytical formulas for determining the force parameters and stress state of abrasive working circles is based on various methods and models of taking into account the physical and mechanical properties of the working bodies of machines in the process of emerging acting forces of interaction with the processing material.

An important aspect of the implementation of the efficiency of cutting natural and artificial stones and cutting grooves in structures and walls is the justification of the reliability of taking into account the processes of heat generation when the working bodies of machines interact with the processing material. The analysis showed the need for special studies to take into account the processes of heat generation based on the theory of thermodynamic processes.

It is necessary to conduct research on the designs of machine working bodies, to clarify and take into account the active forces of interaction of the cutting working body with the working material, to clarify the physical and mathematical model of the "machine - processing material" system.

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Використання машин з дисковим робочим органом для різання високоміцних будівельних матеріалів в умовах виробничих та будівельних майданчиків

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Анотація. На сучасному етапі розвитку обробки твердих матеріалів наука різання матеріалів інтенсивно розвивається у таких кардинальних напрямках, як пошук нових ефективних інструментальних матеріалів; поглиблене вивчення фізики різання; підвищення якості утворених поверхонь разом із потребою інтенсифікації робочих режимів, зокрема, швидкості різання; створення нових ефективних змащувально-охолоджувальних середовищ; дослідження та систематизація досвіду оброблюваності найновіших конструкційних матеріалів – високоміцних і жаростійких сталей і сплавів, синтетичних матеріалів із різноманітними властивостями, вогнетривких матеріалів, графіту і вуглепластиків, деталей з твердих сплавів всіх марок, армованих скловолокном пластмас, різних напівпровідникових матеріалів оздоблюваних матеріалів і виробів з природного каменю; розроблення технічних нормативів на усі відомі види оброблення різанням; оптимізація операцій різання на автоматизованому обладнанні, зокрема на верстатах з ЧПУ та в умовах гнучких автоматизованих виробництв.

Різання природних та штучних кам'яних матеріалів є операцією, у процесі виконання якої підлягає обробленню широка гамма матеріалів з різними фізико-механічними властивостями.

Ключові слова: абразивні армовані круги, різання, високоабразивні матеріали, температура, зв’язка, бічні поверхні.