DOI: 10.65322/j.srd.05192026.19

ANALYSIS OF THERMAL-MECHANICAL FACTORS IN THE PROCESS OF ROAD FREEZE CUTTING

Idiyev Akbar,
E-mail: *akbar.idiyev.97@mail.ru,*
Askarxodjaev Tulkun,
E-mail: *tulkun_ishanovich@mail.ru,*
Pirnaev Sharofiddin,
Department of Engineering Technological Machines,
E-mail: *sharofiddin2306@mail.ru,*
Kayumov Khasanturdi
Department of Computer Science and Computer Graphics,
E-mail: *hasankayimov@gmail.com,*
Tashkent State Transport University

Abstract. *In this article, a comprehensive analysis of the thermal and mechanical loads encountered by the cutters, which are part of the working equipment of the road mill, during the milling of the asphalt concrete layer is carried out. Heat flows generated during milling, stresses in the contact zone, and their influence on cutter wear were studied based on theoretical and mathematical models. In particular, the relationship between cutting forces, the amount of heat released as a result of friction, and the intensity of abrasive wear with a change in the cutter's angle of attack was determined. As a result of the analysis, the expediency of a rational angle of attack for the milling process in the range of 42-43° was scientifically substantiated. This value of the angle allows for extending the service life of the cutters, reducing energy consumption, and increasing the efficiency of the road milling cutter.*

Annotatsiya. *Ushbu maqolada yo‘l frezasining ishchi jihozlari tarkibiga kiruvchi keskichlarga (tishlarga) asfalt-beton qatlamini frezalash jarayonida ta’sir etuvchi issiqlik va mexanik yuklamalar kompleks tahlil qilingan. Frezalash vaqtida hosil bo‘ladigan issiqlik oqimlari, kontakt zonasidagi kuchlanishlar hamda ularning keskichlarning yeyilishiga ta’siri nazariy va matematik modellar asosida o‘rganildi. Xususan, keskichning hujum burchagi o‘zgarishi bilan kesish kuchlari, ishqalanish natijasida ajralib chiqadigan issiqlik miqdori va abraziv yeyilish jadalligi o‘rtasidagi bog‘liqlik aniqlandi. Tahlil natijasida frezalash jarayoni uchun ratsional hujum burchagining* $42-43°$ *oralig‘ida bo‘lishi maqsadga muvofiqligi ilmiy jihatdan asoslandi. Burchakning ushbu qiymati keskichlarning xizmat muddatini uzaytirish, energiya sarfini kamaytirish hamda yo‘l frezasining ish unumdorligini oshirish imkonini beradi.*

Аннотация. *В данной статье проведен комплексный анализ тепловых и механических нагрузок, воздействующих на резцы рабочего оборудования дорожной фрезы в процессе фрезерования асфальтобетонного покрытия. На основе теоретических и математических моделей исследованы тепловые потоки, возникающие при фрезеровании, напряжения в зоне контакта и их влияние на износ резцов. В частности, установлена взаимосвязь между силами резания, количеством теплоты, выделяющейся в результате трения, и интенсивностью абразивного износа при изменении угла атаки резца. В результате анализа научно обоснована целесообразность применения рационального угла атаки для процесса фрезерования в диапазоне* $42-43°$*. Данное значение угла позволяет продлить срок службы резцов, снизить энергозатраты и повысить эксплуатационную эффективность дорожной фрезы.*

Keywords: *road milling cutter, cutter, heat balance, angle of attack, wear.*
Kalit so‘zlar: *yo‘l frezasi, keskich (tish), issiqlik balansi, hujum burchagi, yeyilish.*
Ключевые слова: *дорожная фреза, резец, тепловой баланс, угол атаки, износ.*

DOI: 10.65322/j.srd.05192026.19

Introduction. Road milling cutters operate in extremely complex and difficult operating conditions during the asphalt concrete pavement breaking process. During the milling process, cutters are simultaneously subjected to high mechanical, thermal, and abrasive loads. These loads directly affect the service life of the cutter, cutting efficiency, and the energy efficiency of the entire milling process [1].

The working conditions of the cutter are mainly characterized by strong heat flows, an abrasive environment, and high contact pressures. During the milling process, due to the plastic and elastic properties of the asphalt concrete layer, a complex stress state arises at the cutter-material interface. In this case, along with cutting forces, friction forces and impact loads are also actively involved. As a result, high-temperature zones are formed at the tip of the cutter and on its working surfaces [2].

The main sources of heat generated during the milling of asphalt concrete are:

- initial temperature of the hot asphalt concrete layer (usually 120-160 °C);
- intensive friction between the cutter and the material;
- energy released during the plastic deformation and decomposition of the material;
- Local heating resulting from the cutter's periodic impact on the layer.

Materials and Methods

During the milling of asphalt concrete, the following problems arise related to heat generation. Temperature sources affecting the cutter: [3]

Asphalt temperature: 120-160°C (when milling a hot layer). Friction: can rise up to 250-450°C between the cutter-asphalt and the cutter-coating. Deformation of metal: local heating by impact, friction up to 500°C.

Dependence of attack angle (α) and temperature: Rational attack angle: 42-50° (based on world standards: Wirtgen, Kennametal, Sandvik data). When the angle decreases (α < 40°), the cutter "slides" into the asphalt, and friction increases.

The temperature increases by 20-30% due to changes in friction. With increasing temperature, the sphere softens and wear accelerates. When the angle increases (α > 50°), the cutter "impacts" the asphalt and the impact force increases. The probability of a large impact breaking the tip is +5...8%. The temperature of local asphalt rises above 350°C.

The total heat balance of the cutter is expressed as follows:

$$Q_{general} = Q_f + Q_p + Q_a \quad (1)$$

here: Q_f- heat of friction;

Q_p- heat of sphalte deformation;

Q_a- heat passing through the initial temperature of asphalt.

Q_f. - heat of friction.

This is the heat released from friction at the contact of the cutter with the asphalt (and partly the cutter).

$$Q_f(a) = \mu(a, w) \cdot N(a) \cdot v_s(a)a \quad (2)$$

$\mu(a, w)$- coefficient of friction (increases with increasing wear)

$N(a)$- normal pressure force.

$v_s(a)$- sliding (relative) speed.

Dependence on angle:

$aN(a)$ - changes contact geometry and pressure distribution ⇒ changes.

DOI: 10.65322/j.srd.05192026.19

aQ_f - if the cutter deviates from the norm, "scraping" increases ⇒ increases.

$$Q_f(a) = Q_{fo}\left[1 + k_f(a - a_{rat})^2\right] \quad (3)$$

Q_p. - heat of deformation of asphalt.

In the cut zone of the asphalt concrete layer, sphalte deformation occurs, and most of the work expended is converted into heat.

$$Q_p(a) = \beta \cdot P_{pl}(a) \quad (4)$$

$\beta \approx 0.85 \ldots 0.95$ - the percentage of asphalt work converted into heat.

$$P_{pl}(a) \approx \tau(a) \cdot A_s(a) \cdot v \quad (5)$$

$\tau(a)$ - shear stress

$A_s(a)$- plane (deformation) field

v- cutting speed.

$$Q_p(a) = Q_{po}[1 + p(a - a_{rat})^2] \quad (6)$$

Q_a. - heat coming with the initial temperature of asphalt.

This heat is not generated, but the material itself enters the milling zone (asphalt is initially warm/cold).

$$Q_a(a) = m(a) \cdot c_p \cdot (T_0 - T_{ref}) \quad (7)$$

$m(\alpha) = \rho \cdot Qv(\alpha)$- mass consumption of removed asphalt.

$Qv(\alpha) = b \cdot h(\alpha) \cdot v$ - volumetric consumption.

T_0- initial temperature of asphalt.

Formula for the relationship between total heat and milling angle.

$$Q_{general}(a) = \left(Q_{f0} + Q_{p0}\right) \cdot [1 + K(a - a_{rat})^2] + \\ +\rho \cdot b \cdot h_0 \cdot v \cdot c_p(T_0 - T_{ref}) \cdot \left[1 + k_h(a - a_{opt})^2\right] \quad (8)$$

$$K = k_f + k_p \quad (9)$$

$$\frac{dQ_{general}}{d_a} \approx 0 \Rightarrow \alpha = a_{rat} \quad (10)$$

The following table shows the main parameters adopted in the mathematical modeling of the thermal effect of the road mill cutter during the asphalt concrete milling process, their physical meaning and scientific justification.

Table 1

Main parameters adopted in the mathematical model

Parameter	Designation and unit	Accepted value	Scientific justification
Cutting angle	β, degrees	42°	$\beta \approx 40 - 45°$ According to experimental studies and analysis of the literature, the cutting resistance in the interval is minimal. As a result of the decrease in forces at this angle, heat emission also decreases.
Minimal tangential force	F_{min}, N	≈ 1800 N (for 1 cutter)	The ordinal value of forces, determined in laboratory and production experiments. In the model, it is taken as a reference point and calibrated by real measurements.
Angular sensitivity coefficient	α, 1/grad2	0.001-0.002	Expresses the quadratic increase in forces as a result of deviation from the cutting angle. This approach is widely used in identification models of cutting processes.

DOI: 10.65322/j.srd.05192026.19

Parameter	Designation and unit	Accepted value	Scientific justification
The rate of conversion of mechanical work into heat	μ, -	0.85-0.95 (acceptance: 0.90)	In the processes of plastic deformation and friction, a large part of the mechanical energy is converted into heat (Taylor-Quinney approach).
Fraction of heat transfer to the cutter	φ_{tool}, -	0.3-0.4 (acceptance: 0.35)	Heat distribution is assessed based on thermal effusion. For carbide cutters, this range is found in the literature.
Cutter tip speed	V_c, m/s	2-8 m/s	It is determined based on the drum radius and rotation speed. This range corresponds to practical milling modes.
Ambient temperature	T_∞, °C	20 - 30 °C (acceptance: 25 °C)	Typical value for field conditions. When assessing the relative temperature, it is taken as an initial condition.
Maximum permissible temperature	T_{max}, °C	400 °C	The accepted threshold value from the point of view of thermal stability for hard alloy (WC-Co) cutters and bituminous materials.
equivalent thermal conductivity	G_{th}, W/K	Determined by model	T_{max}Heat conductivity, convection, and contact cooling are represented in aggregate form. Calibrated according to the condition =400°C.

Results

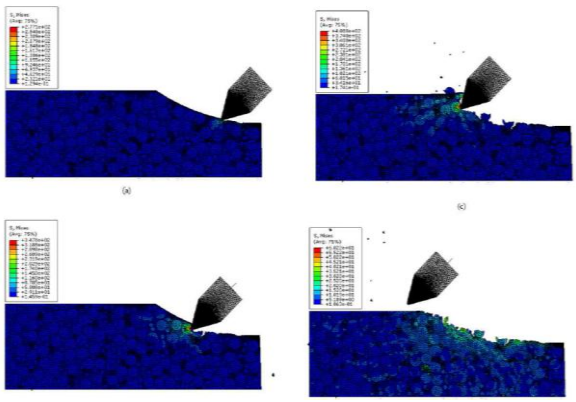

Figure 1. Nephogram of cutting speed: v=0.2 m/sec, v=0.5 m/sec, v=1.2 m/sec, v=1.8 m/sec.

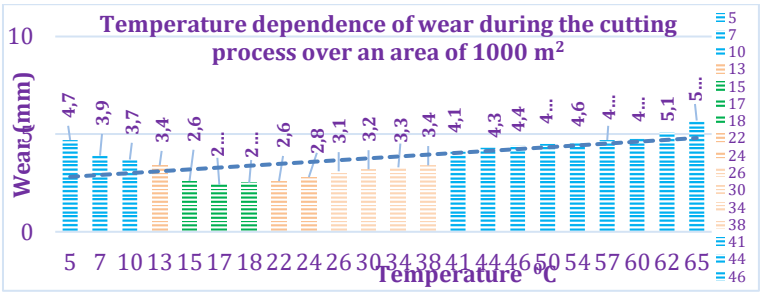

Figure 2. 1000 m² temperature dependence of wear during surface cutting

DOI: 10.65322/j.srd.05192026.19

Table 2. Dependence of the external environment and milling temperature.

Parameter (°C)	Temperature (°C)
5	410
10	386
15	377
22	377
26	380
30	381
38	384
41	387
46	390
50	391
57	395
60	397
62	410
65	415

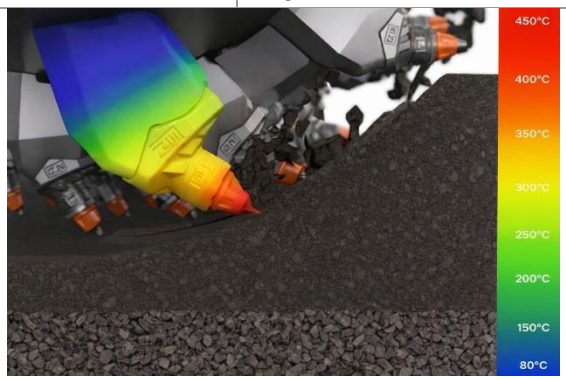

Figure 3. Heat generation in cutters during asphalt concrete milling

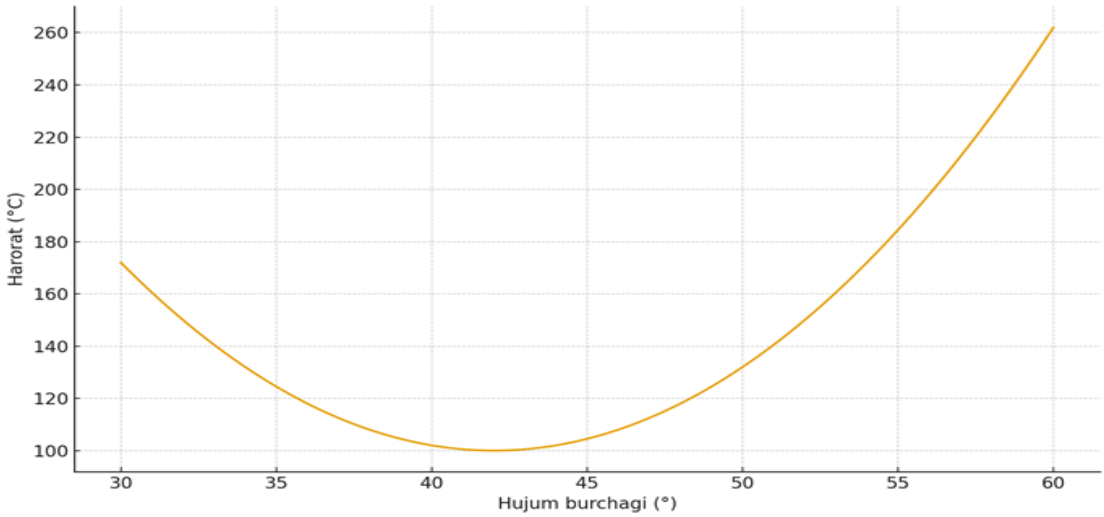

Figure 4: Dependence of the heat generated during milling on the angle of attack

DOI: 10.65322/j.srd.05192026.19

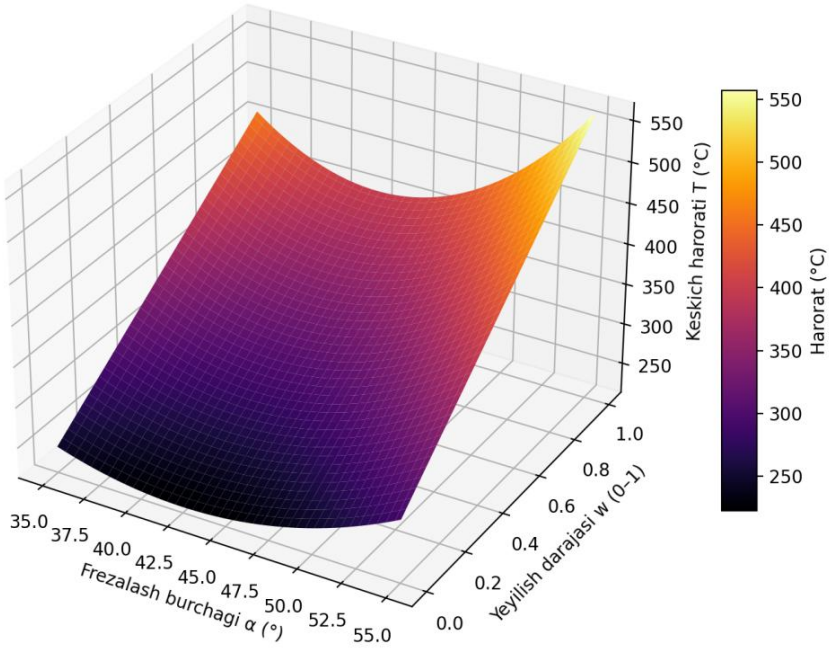

Figure 5: Overall graph of temperature, milling angle, and wear

Analysis of Results. The closer to zero the ratio of the total heat generated and the derivative values of the milling angle, the closer it is to the rational angle.

Discussion. A sharp increase in the amount of heat negatively affects the mechanical properties of the cutter material. In particular, the appearance of microcracks, weakening of the binder phase, and thermal fatigue phenomena are observed in tungsten-carbide tip cutters under the influence of high temperatures [4]. This leads to rapid wear of the cutter and a reduction in its service life

The cutter's angle of attack (cutting angle) also plays an important role in the heat generation process. When the angle of attack is not optimal, the cutting process occurs due to more sliding and friction than effective fragmentation. As a result, cutting forces increase, heat generation increases, and abrasive wear on the cutting surface accelerates. On the contrary, a correctly chosen angle of attack stabilizes the cutting process, reduces energy consumption, and decreases the wear intensity of the cutter [5].

For the purpose of heat control, water spraying systems are widely used in modern road milling machines. Water spraying not only reduces the heat generated by friction between the cutter and asphalt concrete, but also limits dust formation. At the same time, the cooling process serves to maintain the structural stability of the cutter material and extend its service life [6].

Thus, excessive heat, along with friction and impact loads, is one of the main factors leading to rapid wear of cutters. In-depth scientific analysis of these processes, optimization of the angle of attack, improvement of cooling systems, and development of cutting materials are of great importance in increasing the efficiency of road milling machines [7].

Conclusion. According to the results of the conducted analytical and theoretical studies, it was established that the efficiency and service life of road milling cutters are directly related to the thermo-mechanical loads arising during the milling process. The occurrence of high temperatures during milling reduces the stability of the cutter's rotation and accelerates the processes of abrasive and thermal wear of the working edge. As a result, the cutter's resource is significantly reduced.

Studies have shown that at small values of the angle of attack, the friction forces between the cutter and asphalt concrete increase, which leads to a sharp increase in heat generation in the

DOI: 10.65322/j.srd.05192026.19

contact zone. Conversely, with excessively large attack angles, the impact loads intensify, and local heating and contact stresses are distributed unevenly. This condition leads to the appearance of microcracks at the tip of the cutter and their rapid breakage.

It was established that reaching a temperature in the range of 300-450 °C during milling significantly increases the probability of brittleness of the tungsten carbide cutter ends, and also leads to a decrease in the mechanical strength and hardness properties of the steel body. Based on the conducted mathematical and physical analysis, it was scientifically substantiated that the rational angle of attack for the milling process is in the range of 42-43°. At the same time, it was established that under conditions of working with hot asphalt concrete and high friction intensity, the value of the optimal angle of attack can shift in the range of 1-5° depending on technological factors. These results have important scientific and practical significance for increasing the efficiency of road milling cutters, extending the service life of cutters, and reducing operating costs.

Data availability statement

The datasets generated during and or analyzed during the current study are available from the corresponding author on reasonable request.

Author contributions

Akbar Idiyev developed a mathematical model, performed analytical calculations, and prepared the original manuscript. The research was supervised by Pirnaev Sharofiddin, who contributed to the development of the methodology, reviewed and edited the manuscript. Askarhodjaev Tulkun gave scientific advice, reviewed and edited the manuscript. Kayumov Khasanturdi reviewed and edited the manuscript. All authors approved the final version of the manuscript.

References

1. Pirnaev, S., Mukhitdinov, A., Saydaliyeva, D., & Tulaboyeva, G. (2024). Economic effectiveness of choosing and based on the method of spraying the plasma coating to road milling cutters. AIP Conference Proceedings, 3045(1), 060034.

2. Pirnaev, Sh. A., Rustamov, K. J., Mukhitdinov, A. S., Nurtas, M., & Rustamova, N. R. (2025). Influence of milling depth and angle of attack on parameters of power device. AIP Conference Proceedings, 3256, 060019.

3. Kennametal Inc. (2020). Road milling tools: Technical guide. Kennametal Inc.

4. Rabat, O., Pirnaev, Sh., Rustamov, K., Usmanov, I., Shermatov, Sh., & Magdiev, K. (2024). Development of corrosion-resistant material for asphalt concrete cutting part. E3S Web of Conferences, 587, 03012.

5. Pirnaev, S., Sindarov, R., Dzhumabeva, F., & Saidova, S. (2021). Technique for experimental studies of asphalt concrete milling process. E3S Web of Conferences, 264, 02016.

6. WIRTGEN. (n.d.). Cold milling machine W 250 XF [Product brochure, p. 40]. Retrieved October 8, 2026, from https://www.wirtgen-group.com/binary/full/o337710v77_W_250_XF_Brochure_Datasheet_ENGB.pdf

7. Rabat, O., Pirnaev, S., Saydaliyeva, D., Tulaboyeva, S., & Rustamov, K. (2024). Strengthening the protective layer of road milling machines using a combined method. ICTEA: International Conference on Thermal Engineering.