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Theoretical Study of the Machinability of White Cast Iron During Mechanical Cutting

A.A. Allanazarov[1], T.U. Pardayev[2], U.S. Khusanov[3]

[1] Associate Professor, PhD, Termez State University of Engineering and Agrotechnologies
[2] Senior Lecturer, Yangiyer Branch of Tashkent Institute of Chemical Technology
[3] Senior Lecturer, Termez State University of Engineering and Agrotechnologies

Abstract: This paper presents a theoretical study of the machinability of white cast iron during mechanical cutting. The results obtained for determining the cutting speed that satisfies production time standards are based on the material of the cutting tool and the optimal cutting temperature for white cast iron. The findings of the theoretical analysis indicate that, during the machining of white cast iron, the cutting performance of VK group tools is strongly influenced not only by the high hardness of hard alloys but also by their physical properties, including thermal conductivity and heat capacity.
Keywords: White cast iron, hard alloy, insert, cutting process, machining, machinability, cutting speed

Introduction

During the mechanical cutting of metals, the cutting tool is subjected to significant operational loads, elevated temperatures, and chemical interactions with the workpiece material. Based on the theoretical study of the machining process and the machinability of white cast iron, this research aims to identify the key properties of cutting tools that significantly influence machining efficiency.
In metal cutting operations, the cutting speed v_0 must ensure compliance with the specified optimal time standards while maintaining the required cutting temperature θ and cutting force P_z. If the selected cutting speed does not satisfy these requirements, it must be reduced, which in turn leads to a significant decrease in production efficiency.

Materials and Methods

To determine the machinability of materials under production conditions, S.S. Silin proposed an equation for calculating the optimal cutting speed, which can be expressed as follows [1]:

$$v_0 = \frac{k^2 \lambda c_p a_1 b_1^2 E^{0,2}}{4\sin^{0,1}} \left(\frac{\theta_o}{P_{z\min}}\right)^2 \times \left[1 + \sqrt{1 + \frac{2,65\lambda_p \beta\varepsilon \left(\frac{a_1}{b_1}\right)^{0,3} P_{z\min}}{k^2 a_1 b_1 \lambda c_p E^{0,25} \sin^{0,065}\alpha\theta_o}}\right]^2 . \quad (1)$$

Here, $P_{z,min}$ represents the minimum cutting force required to ensure a stable execution of the machining process, expressed in Newtons (N).
The value of the cutting force $P_{z,min}$, which guarantees the stable minimum operation of the mechanical cutting process, is determined by the following formula:

$$P_{z\min} = \frac{\tau_p a_1 b_1 c_o E^{n_o} (1 - 0,45\sin\gamma) M^{0,04}}{\sin^{0,14}\alpha}, \quad (2)$$

bunda $c_o = 3,65;\ E \leq 0,05$ *da* $n_o = 0,125; \geq$
$c_o = 5,31;\ 0,05 \leq E \leq 0,1$ *da* $n_o = 0,25;$
$c_o = 7,60;\ E \leq 0,1$ *da* $n_o = 0,4;$

All parameters involved in Equation (2) can be predetermined (planned), which makes it possible to calculate the cutting force that ensures the machining process is carried out under stable minimum force conditions for a given material.

Discussion of Results

By substituting Equation (2) into Equation (1), we obtained the following expression for calculating the optimal cutting speed in the mechanical machining of materials:

$$v_0 = \frac{k^2 \lambda c_p \sin^{0,2} \alpha \left(\dfrac{\theta_o^2}{\tau_p^2} \right)}{4 a_1 c_o^2 \left(\dfrac{\rho_1}{a_1} \right)^{2(n_o - 0,1)} (1 - 0,45 \sin\gamma) \left(\dfrac{b}{b_1} \right)^{0,08}} \times$$
$$\times \left[1 + \sqrt{1 + \frac{2,65 \lambda_p \beta \varepsilon \left(\dfrac{a_1}{b_1} \right)^{0,3} c_o \left(\dfrac{\rho_1}{a_1} \right)^{n_o} (1 - 0,45 \sin\gamma) \left(\dfrac{b}{b_1} \right)^{0,04} \tau_p}{k^2 \lambda c_p \sin^{0,2} \alpha \theta_o}} \right]^2 . \quad (3)$$

From Equation (3), it is possible to predict the required physical–mechanical properties and geometric parameters of the cutting tool that ensure the cutting speed v0v_0v0 meets production time standards for a given material.
Using this expression, we performed a comparative analysis of the machinability of white cast iron and other steels. For this purpose, the following initial parameters were defined:
k = 3,4; t = $2\cdot10^{-3}$ *m*; s = $0,2\cdot10^{-3}$ *m*; γ = 10°; α = 10°; φ = 45°; φ_1 = 45°; r = $1\cdot10^{-3}$ *m*; ρ_1 = $0,01\cdot10^{-3}$ *m*; β = 1,22 *рад*; ε = 1,57 *rad*.
Based on the given initial data, Equation (3) can be transformed into the following expression:

$$v_0 = 1,45 \cdot 10^3 \lambda c_p \left(\frac{\theta_o}{\tau_p} \right)^2 \left[1 + \sqrt{1 + 0,625 \frac{\lambda_p}{\lambda} \frac{\tau_p}{c_p \theta_o}} \right]. \quad (4)$$

Using Equation (4), we calculated the optimal cutting speed for efficient machining of white cast iron with a VK6-grade carbide insert [2]. The results obtained during the calculations are presented in Table 1.

Table 1

Results of calculating the optimal cutting speed for machining white cast iron using VK6V, VK6, VK6M, and VK6OM grade carbide tools

λ_p, *J/(m·c·°C)*	λ, *J/(m·c·°C)*	$c_p \cdot 10^{-6}$, *J/(m³·°C)*	$\lambda c_p \cdot 10^{-6}$, *J²/(m⁴·°C)*	$\tau_p \cdot 10^{-6}$, *N/m²*	θ_o, *°C*	v_o, *m/s*
ВК6В						
58,5	38,7	4,5	174,1	3000	900	0,0214
ВК6						
56,7	38,7	4,5	174,1	3000	850	0,0189
ВК6М						

55,9	38,7	4,5	175,1	3000	800	0,0176
BK6OM						
54,7	38,7	4,5	174,1	3000	750	0,0143

The results obtained in determining the cutting speed that meets production time standards, based on the cutting tool material and the optimal cutting temperature for machining white cast iron, indicate that the currently recommended carbide grades VK4, VK6V, VK6, VK6M, and VK6OM do not fully satisfy the requirements imposed on the cutting process in industrial applications [3].
At the same time, carbide materials with coarse-grained tungsten carbide, such as VK4V and VK6V, demonstrated slightly better performance compared to carbides with fine and ultrafine tungsten carbide grain structures.

Conclusion

The results of the theoretical analysis of the mechanical machining process of white cast iron indicate that the cutting performance of VK group tools is significantly influenced not only by the high hardness of cemented carbides but also by their physical properties, such as thermal conductivity and heat capacity.
Taking this into account, it can be concluded that the use of carbide materials with ultra-coarse tungsten carbide grains is more appropriate for the mechanical machining of white cast iron.

References

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