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WAYS OF INCREASING THE MACHINABILITY OF HIGH-STRENGTH CAST IRON

**PhD (Tech.) N. Lalazarova, PhD (Tech.) G. Komarova, PhD (Tech.) O. Afanasieva,
PhD (Tech.) O. Popova**

НАПРЯМИ ПІДВИЩЕННЯ ОБРОБЛЮВАНОСТІ ВИСОКОМІЦНОГО ЧАВУНУ

Кандидати техн. наук Н. О. Лалазарова, Г. Л. Комарова, О. В. Афанасьєва, О. Г. Попова

Abstract. *Industry is in need of high-strength cast irons with a high level of operational properties. The problem is that such cast iron is characterized by a low level of machinability by cutting. The work presents the results of research in the following areas of improving machinability: heat treatment of cast iron, machining and hardening of hard alloy tools, processing using a polymer-containing lubricating and cooling fluid.*

Keywords: *high-strength cast iron, machinability, heat treatment, work-hardening treatment, lubricating and cooling fluid.*

Анотація. *Промисловість потребує високоміцних чавунів із високим рівнем експлуатаційних властивостей. Проблема полягає в тому, що такі чавуни мають невисокий рівень оброблюваності різанням. Метою є розроблення комплексу методів покращення оброблюваності високоміцного чавуну, які стосуються властивостей оброблюваного матеріалу, інструменту і характеру їхньої взаємодії. Для дослідження структури використовували оптичний цифровий мікроскоп, зносу інструменту – інструментальний мікроскоп. Тангенціальну складову сили різання та її коливання досліджували за допомогою спеціального динамометра. У роботі наведені результати досліджень із таких напрямів покращення оброблюваності: термічна обробка чавуну, обробно-зміцнююча обробка твердосплавного інструменту, обробка з використанням полімервмісної змащувально-охолоджуючої рідини. На оброблюваність значний вплив має хімічна і структурна неоднорідність чавуну, пов'язана з ліквацією хімічних елементів. У роботі неоднорідність* *високоміцного чавуну визначають за коливаннями динамічної складової сили різання, а відносну оброблюваність – відносно неоднорідності сірого чавуну, який прийнято як еталон. За оптимальний режим термічної обробки запропоновано нормалізацію з міжкритичного інтервалу, яка зменшує неоднорідність чавуну та одночасно забезпечує достатньо високий рівень експлуатаційних властивостей за перерізом деталі і є найбільш економічною. Неоднорідність чавуну сприяє інтенсифікації зносу інструменту. Проведення нормалізації дає змогу підвищити швидкість різання при точінні гексанітом-Р в 1,2 раза. Наприклад, комплексний підхід до покращення оброблюваності (використання обробно-зміцнюючої дробоструминної обробки твердосплавного інструменту і полімервмісної ЗОР) дає змогу підвищити швидкість різання при точінні високоміцного нормалізованого чавуну відносно литого стану з* $V_{60} = 2{,}5$ *м/с до* $V_{60} = 4{,}5$ *м/с.*

Ключові слова: *високоміцний чавун, оброблюваність, термічна обробка, обробно-зміцнююча обробка, змащувально-охолоджуюча рідина.*

Introduction. Currently, high-strength nodular graphite cast iron (HSNGCI) is widely used as a structural material, which combines the manufacturability of gray cast iron with a set of properties higher than those of ductile and, in some cases, even cast and forged steel [1]. The expected significant growth in the world production of vehicles and engineering products will increase the demand for cast iron products and their nomenclature.

In this regard, the industry needs to use cast irons with a high level of operational properties, whose introduction is restrained by the low level of their machinability by cutting.

Analysis of recent research and publications. The properties of the material are determined by its composition and structure. Cast irons are characterized by significant chemical and structural inhomogeneity. A wide range of operational properties of cast iron are obtained by changing the chemical inhomogeneity and structure of the metal matrix [2, 3]. Favourable casting properties make it possible to make high-quality castings with minimal wall thickness from high-strength nodular graphite cast iron [4].

Distribution shafts and crankshafts of cars, combine harvesters, diesel locomotives, toothed gears and other parts that work in difficult conditions are made of high-strength cast iron: they are subjected to variable loads, significant contact pressure, and actively wear out. To obtain the necessary set of properties, cast iron products are alloyed and subjected to strengthening heat treatment [5]. In this regard, production is faced with the need to process not only low-strength cast irons, but also cast irons subject to hardening treatment in various modes, which are selected based on the working conditions of the parts [6].

Due to the fact that cast irons have significant chemical and structural inhomogeneity and can have a high level of mechanical properties, they are characterized by low machinability.

Machinability by cutting is a complex of technological characteristics that determine the efficiency of material processing. It is the most important factor affecting productivity, quality and cost of production. Despite this, there is no generally accepted approach to the problem of machinability.

A systematic approach to machinability involves its comprehensive consideration, since an isolated study of any, even an important indicator, cannot lead to an optimal solution in terms of the entire complex of properties [7].

Machinability can be evaluated by a large number of parameters: cutting force and temperature, chip shrinkage, cutting speed, wear intensity, tool stability, chip volume, cost and productivity of processing, quality characteristics of the surface layer of the part, relative machinability coefficient, energy characteristics, etc.

The choice of one or another machinability indicator depends on the needs of production and its goals. For example: under conditions of shortage of any type of cutting tool, you should choose an indicator that ensures a decrease in its costs (maximum stability); with high requirements for the quality of the treated surface – roughness and other quality indicators, etc.

Information can be found in the literature on determining the machinability of high-strength cast iron by stability indicators, by the coefficient of relative machinability (relative to the machinability of gray cast iron), by empirical dependencies (by chemical composition, by mechanical properties – hardness, strength, plasticity indicators).

Thus, machinability is a complex concept that is determined by the state of the processed material, the cutting tool and the nature of their interaction. The main factors stemming from the features of the composition and structure of cast iron, which ensure the machinability of high-strength nodular graphite cast iron, are: inhomogeneity, microstructure and hardness of cast iron.

It is possible to improve the machinability of high-strength nodular graphite cast iron in the following ways: regardless of the cutting process, due to various actions on the material of the product; due to the influence on the tool and processing conditions during the cutting process.

The first group combines the methods of changing machinability, which are carried out before the process of mechanical processing and independently of it, for example, during the metallurgical cycle due to a change in the chemical composition during the manufacture of the workpiece, due to heat treatment. These factors can be used if it is technologically and economically possible to change the technology of the casting process, if the processes of additional alloying and heat treatment do not have a negative effect on obtaining the required set of properties of the processed part.

Annealing cast iron to improve machinability is usually an intermediate operation, after which it is necessary to carry out final processing, which makes the process of obtaining a finished product significantly longer and more expensive.

The second group includes methods of improving machinability, which are implemented in the process of cutting: changing the properties, design, and geometry of the tool. In many cases, this is the easiest way to solve the machinability problem. It is promising to use tool-hardening treatment, whose possibilities when cutting high-strength nodular graphite cast iron have not yet been studied.

The third group includes methods that affect the nature of the interaction of the tool with the processed workpiece: elements of the cutting mode, lubricating and cooling fluid (LCF), heating cutting, with anticipatory plastic deformation, etc. [7]

The use of LCF is a promising direction, as currently a large number of universal LCF with a huge spectrum of action have been created.

Machinability can be improved by using either one of the methods (for example, heat treatment). More efficiency can be achieved by using several methods at the same time. Since machinability is a complex concept, in order to improve it, it is necessary to develop a set of methods that would have to do with the properties of the processed material, the tool, and the nature of their interaction.

Based on the analysis of literary data, the purpose and objectives of the research were determined.

Goal and task setting. The goal is to develop a complex of methods for improving the machinability of high-strength cast iron, which deal with the proper-ties of the processed material, the tool, and the nature of their interaction.

In order to achieve the set goal, it is necessary to give the reasons for the low machinability of high-strength nodular graphite cast iron; to develop recommendations for improving the machinability of cast irons by heat treatment, tool hardening treatment and the use of LCF.

The main part of the study. The machinability of high-strength cast iron is determined by its chemical (especially silicon liquation) and structural inhomogeneity (in cast iron, ferrite is located around graphite inclusions), which causes fluctuations in the dynamic component of the cutting force and negatively affects the stability of the cutting tool (Fig. 1).

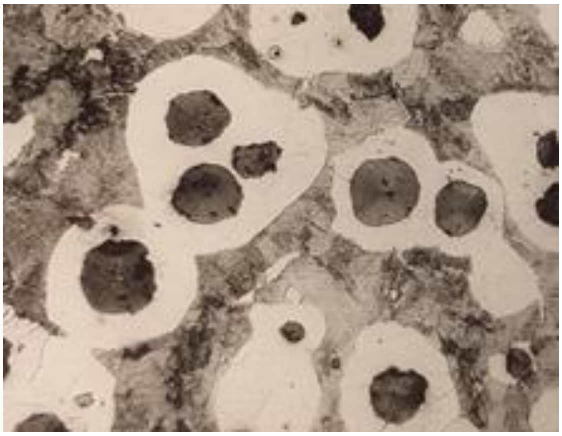

Fig. 1. Microstructure of cast iron in the cast state

An optical digital microscope was used to study the microstructure.

This implies the method of improving machinability by heat treatment, which affects the degree of inhomogeneity of cast iron.

The degree of inhomogeneity of cast iron is determined by the results of statistical processing of fluctuations in the tangential component of the cutting force, which was studied using a special dynamometer:

$$K_н = \frac{\nu_{вч}}{\nu_{сч}} \quad . \tag{1}$$

where $\nu_{вч}$ – is the coefficient of variation of the instantaneous values of the cutting force for high-strength nodular graphite cast iron;

$\nu_{сч}$ – is the coefficient of variation of instantaneous cutting force values for gray cast iron.

The coefficient of inhomogeneity, as a complex characteristic of cast iron, determines its machinability $K_о$ – coefficient of relative machinability

$$K_o = \frac{K_{н_{сч}}}{K_н} = \frac{1}{K_н} \quad . \tag{2}$$

For practical application, it is necessary to know the absolute value of machinability. Estimated values of cutting speeds at a durability of 60 min were determined for the investigated cast irons when processed with superhard tool material – hexanite-P:

$$V_{60} = K_o \cdot V_{сч} \; , \tag{3}$$

where $V_{сч}$ is a cutting speed when processing gray cast iron, m/s.

As indicators of machinability, the ratio of relative machinability and cutting speed at a durability of 60 min was used.

Cast iron is characterized by an increased degree of inhomogeneity and a reduced level of machinability ($K_n = 1{,}7$, $K_o = 0{,}6$,

V_{60} = 3,0 m/s). Traditionally, annealing is used to improve the machinability of cast iron, which evens out chemical and structural inhomogeneity, reduces hardness, and significantly improves machinability (K_n = 1,1, K_o = 0,9, V_{60} = 4.8 m/s). However, annealing increases the time of cast iron processing, reduces its productivity, and requires one more processing – the final one, which ensures obtaining the required set of properties in the cross-section of the part. The analysis of literary sources showed that normalization from the inter-critical interval (ICI) can be such a heat treatment. It reduces the inhomogeneity of cast iron, respectively, improves machinability relative to the cast state and provides a high level of mechanical properties ($K_{н}$ = 1,36, K_o = 0,73, V_{60} = 3,6 m/s). The given research results confirm that machinability is determined by the inhomogeneity of cast iron and normalization with ICI can be considered the optimal heat treatment, both in terms of machinability and economy. For processing cast iron, an ultra-hard tool material based on cubic boron nitride - hexanite-P is used, which has a high level of physical and mechanical properties, and is inert to the processed material.

A high degree of inhomogeneity of cast iron contributes to the intensification of the cutting tool wear. Carbide tools are most often used when processing products from high-strength nodular graphite cast iron. One of the ways to increase its wear resistance is the processing and strengthening treatment.

When processing cast iron, cyclic loads occur, causing periodic changes in tangential and normal stresses on the contact surfaces of the tool, which causes chipping of the cutting edge. These stresses affect the bonding and the carbide phase of the hard alloy in different ways. Therefore, hard alloy wear at high speeds occurs either as a result of fatigue destruction of carbide grains, when small particles are removed from their worn surface, or due to the removal of carbide grains as a result of fatigue destruction of the bond.

The research was carried out on high-strength cast iron with a hardness of 275–285 HBW after normalization during turning using cutters with pentagonal plates made of BK8 hard alloy, which have the following geometric parameters: φ = 60 °, φ_1 = 10 °, γ = -8 °, γ = 8 °.

The plates were subjected to vibro-abrasive and shot-blast hardening. Vibro-abrasive processing was carried out on a special BM40C vibro-abrasive machine. The plates were strengthened in the environment of the battle of abrasive circles of 10–20 mm granulation weighing 60 kg, with a frequency of 46 Hz, an amplitude of 0,6 mm. All plates were strengthened simultaneously with continuous washing with soda solution. The properties of the tool during vibro-abrasive hardening are increased due to the optimal radius of rounding of cutting edges and tops, low roughness of cutting surfaces and edges, favourable surface relief, as well as slander, allotropic transformations and residual stresses in the surface layer at a depth of up to 0.01 mm [8].

Shot blast hardening was carried out on a special tool set with a shot-blasting wheel with a diameter of 350 mm and a rotation frequency of 3600 min^{-1}. At the same time, 6 plates, fixed on the cover of the installation in a special device, were strengthened with shot DCK-0.3 without LCFs.

Tool stability T (min) was used as a machinability characteristic. The cutting mode was: t = 0,4 mm; S = 0,07 mm/rev; V = 5,2 m/s. The wear criterion (0.6 mm), the value of resistance (7 – 20 min) and the level of cutting modes were close to those used in production. To reduce the complexity of the experiments, the cutting speed was slightly forced, each experiment was repeated 4 times.

The plates were tested on a 16K625 machine during longitudinal turning without LCF. Strength tests were carried out by gradually increasing the feed until the plate breaks – S_p (mm/rev). With a cutting depth of 2,5 mm and a cutting speed of 0,32 m/s, the feed was increased from 0.78 mm/rev according to the number of machine feeds, each experiment was repeated 10 times. The dimensions and topography of the fractures were close to those during turning of gray cast iron. Tool wear was measured under an instrument microscope.

The tests showed that after vibro-abrasive processing, the maximum value of strength (amount of fracture feed) was obtained for the radius of the cutting edge rounding $\rho = 20$ µm.

The maximum stability and strength of the tool during shot blasting is ensured by shot blasting for 80 s due to a small rounding of the cutting edges and the creation of residual compressive stresses in the surface layer. The level of compressive residual stresses in the surface layer reaches 1200 MPa for the carbide phase, and 400 MPa for the cobalt phase. Shot-blast hardening of the tool is more effective than vibro-abrasive when processing high-strength cast iron.

An effective way to improve machinability is the use of LCF.

The application of LCF for the purpose of intensification of mechanical processing of parts from high-strength nodular graphite cast iron has not yet been widely used [9]. The greatest reduction in axial cutting force, drilling moment and increase in tool stability during drilling is provided by Ukrinol-1 LCF, and OCM-3 when threading. However, the research has not covered a significant group of liquids with a higher level of functional properties. These are polymer-containing multifunctional liquids, whose use in the processing of cast iron parts is promising.

The mechanism of action of polymer-containing media is based on the Rebinder effect. A polymer-containing liquid, for example, of the MXO-69 brand, facilitates the plastic deformation and destruction of normalized cast iron (the coefficient of shrinkage during processing of cast iron is reduced by 20 %), which contributes to the reduction of all component cutting forces (reduction of the component cutting force P_z by 18–20 %), the coefficient of friction is reduced (by 16–18 %), which helps to lessen the cutting temperature.

The presence of a polymer-containing medium affects the nature of chip formation, improves chip dispersion, and conditions for its removal from the cutting zone.

Treatment with a polymer-containing liquid ensures a 30% reduction in the roughness of the treated surface of normalized cast iron. The roughness was measured with a TR200 model roughness meter.

The use of a polymer-containing liquid when turning normalized high-strength cast iron with a carbide tool provides a 1,4-fold increase in cutting speed.

Thus, a comprehensive approach to improving machinability (for example, the use of tool hardening treatment, polymer-containing LCF) allows to increase the cutting speed when turning high-strength normalized cast iron relative to the cast state from $V_{60} = 2{,}5$ m/s to $V_{60} = 4{,}5$ m/s.

Conclusion. The reduced machinability of high-strength nodular graphite cast iron is explained by its high degree of chemical and structural inhomogeneity.

Machinability as a complex concept requires a complex approach to its improvement.

Heat treatment allows to reduce the degree of inhomogeneity of cast iron and improve its machinability relative to the cast state. Normalization with inter-critical interval is a rational mode of heat treatment, in terms of machinability and ensuring the required level of operational properties.

The use of machining and strengthening shot blasting of a carbide tool helps to significantly increase its strength and stability.

Mechanical processing using a polymer-containing LCF, which has a multifunctional effect on the cutting process, makes it possible to increase the cutting speed by 1,4 times when processing with a carbide tool.

For example, a comprehensive increase in the machinability of cast iron using tool hardening treatment and polymer-containing LCF allows almost doubling the cutting speed with a hard alloy tool.

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Lalazarova Nataliia, PhD, Associate Professor, Department of Technology of Metals and Materials Science. https://orcid.org/0000-0002-2138-9081. Tel.: +38 (095) 390-38-16. E-mail: lalaz1932@gmail.com. Kharkiv National Automobile and Highway University.
Komarova Hanna, PhD, Associate Professor, department of wagon engineering and product quality. https://orcid.org/ 0000-0001-8597-58-91. Tel.: +38 (067) 999-85-77. E-mail: anna.kom3793@gmail.com. Ukrainian State University of Railway Transport.
Afanasieva Olga, PhD, Associate Professor**,** Physical Foundations of Electronic Engineering Department. https://orcid.org/0000-0002-5382-2986. Tel.: +38(096)-525-62-35. E-mail: 7584839@ukr.net. National University of Radio Electronics.
Popova Olena, PhD, Associate Professor, Department of Composite Structures and Aviation Materials. https://orcid.org/0000-0003-3955-3852+38. Tel.: +38 (067) 570-12-17. E-mail: o.popova@khai.edu/. Kharkiv National Aerospace University «Kharkiv Aviation Institute».

Лалазарова Наталія Олексіївна, кандидат технічних наук, доцент кафедри технології металів та матеріалознавства, Харківський національний автомобільно-дорожній університет. https://orcid.org/0000-0002-2138-9081. Тел.: +38 (095) 390-38-16. E-mail: lalaz1932@gmail.com.
Комарова Ганна Леонідівна, кандидат технічних наук, доцент кафедри інженерії вагонів та якості продукції, Український державний університет залізничного транспорту. https://orcid.org/ 0000-0001-8597-58-91. Тел.: +38 (067) 999-85-77. E-mail: anna.kom3793@gmail.com.
Афанасьєва Ольга Валентинівна, кандидат технічних наук, доцент кафедри фізичних основ електронної техніки, Харківський національний університет радіоелектроніки. https://orcid.org/0000-0002-5382-2986. Тел.: +38 (096) 525-62-35. E-mail: 7584839@ukr.net.
Попова Олена Георгіївна, кандидат технічних наук, доцент кафедри композитних конструкцій та авіаційного матеріалознавства, Харківський національний аерокосмічний університет ім. М. Є. Жуковського «ХАІ». https://orcid.org/0000-0003-3955-3852+38. Тел.: +38 (067) 570-12-17. E-mail: o.popova@khai.edu.

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