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# High-efficiency machining of materials used in heavy power engineering

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**Abstract**

The study considered issues for improving the efficiency of machining materials used in heavy power engineering on the basis of the development of carbide tools with nanostructured multilayer coatings (NMCC) of high wear resistance. The following compositions of the NMCC were developed for investigation: Ti-TiN-(TiCrAl)N; Zr-ZrN-(ZrNbCrAl)N; Cr-CrAlN-(NbZrCrAl)N; Zr-ZrN-(ZrCrAl)N. Wide-ranging studies of various properties and characteristics of elaborated NMCC, as well as contact parameters of cutting and wear mechanisms for the carbide tools with various compositions of NMCC are used in high-efficiency longitudinal turning material of heavy power mechanical engineering. Received results of research in this study allow establishing a rational coating composition for deposition on carbide tools providing increase of machining efficiency of the materials used in heavy power engineering.

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*Keywords:* carbide; cutting tool; PVD-coating; physical vapour deposition (pvd); hard machining

**Table of abbreviations**

**HPC** high performance cutting
**EP302-SH** chrome-nickel austenitic steel (analog DIN EN 10088-1: X8CrNiNb16-13, 1.4961; C 0,08-0,12%, Cr 14–16%, Ni 8–10%, Si 2,2–3%, Nb 0,7–1%)
**NMCC** nanoscale multilayer composite coatings
**TT10K8B** carbide (WC-82%; TiC-3%; TaC-7%; Co-8%)
**FCVAD** filtered cathodic vacuum arc deposition

## 1. Introduction

HPC technologies are widely used for machining of products used in heavy power engineering [1,2,3]. Significant volumes of cut chips are typical for HPC processes and contribute to a considerable increase in strength and power of cutting, which requires the use of machines equipped with high-power drives [2,3,4]. Significant problems arise from the use of HPC processes. In particular, high thermomechanical strains acting on contact areas of tools in connection with the removal of large volume of chips substantially intensifies tool wear. Therefore, when the HPC technology is used, a high priority task to enhance their effectiveness is to increase the tool performance [1-4]. Despite the relatively low physical and mechanical properties of materials used in heavy power engineering such as steel EP302-SH as compared with the corresponding figures for hard-to-cut nickel alloys, the complexity of roughing machining of such materials is extremely high.

The tool material for HPC of inserts was developed on the basis of a composite material, comprising carbide substrate and NMCC [4,6,7]. Such composite tool material is characterized by high values of surface hardness, thermal resistance, and physical and chemical inertness with respect to the material being machined. It is characterized by a balanced combination of the values of strength, toughness and fatigue limit [4,6,7]. The cutting part of a tool made of such tool material is characterized by the maximal balanced combination of fragile and plastic strengths. The study used tools with enhanced stiffness of mounting the carbide insert to


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a holder [3].

In order to form the modified tool coatings, the study used innovative processes of filtered cathodic vacuum arc deposition (FCVAD) to effectively implement the concept of gradient, metastable, multi-component, multilayer or super-lattice coatings [3,4,6-10]. The FCVAD processes can create coatings, comprising both metastable and multi-component materials in a single geometric body and thus combine different functional concepts of individual layers in a multilayer coating [6,7,10].

Architecture and design of NMCC was developed on the basis of phenomenological role of the coating as an intermediate technological environment to improve the properties of carbide substrate (hardness, physical and chemical inertness, thermal resistance, oxidation resistance, etc.) and at the same time to reduce thermomechanical loading on contact areas of a tool resulting in its wear. This concept became a basis for systematization of general requirements for coatings deposited on carbide substrates and for justification of the choice for their multilayer composite architecture [4].

During the formation of NMCC with three-layer architecture, compounds with metal/covalent mixed bondings (TiAlN, TiCrAlN, CrAlN, ZrCrAlN, etc.) were used for the outer layer; during the deposition of the adhesive sublayer, the preference was given to elements and compounds with metallic bonding (Ti, Cr, TiN, CrN, etc.); and during the formation of intermediate layers, compounds with ionic bondings (SiC, $Si_3N_4$, $Al_2O_3$, AlN, etc.) were used.

Thus, a main objective of this study was to increase the efficiency of roughing machining of workpieces made of materials used in heavy power mechanical engineering by utilizing cutting tools with high wear resistance made of carbide substrate with.

## 2. Technological background

Specific manufacturing features of large-size products in heavy power engineering are related to the properties of the material of workpieces after pre-machining (for example, forging). Surfaces of such workpieces include solids and are characterized by surface roughness and sufficient geometric tolerances, which necessitate the removal of the significant volumes of the material being machined [5-9].

A typical detail of large-size products of heavy power engineering is a reactor vessel made of steel. Besides, other large-size products of heavy engineering are also widely used (rotors, collectors, tube sheets, etc.), whose workpieces are subjected to further machining after forging. Such products are manufactured from various structural materials, for example, from low-alloy steel, as well as from high-alloy corrosion resistant, heat resistant and temperature resistant steels.

## 3. Techniques of testing

*Methods for coating formation.*

For coating deposition, a vacuum-arc VIT-2 unit was used, which was designed for the synthesis of coatings on substrates of various tool materials. The unit is equipped with an arc evaporator with filtration of vapour-ion flow, which significantly reduces the formation of droplet phase during the formation of coating [7].

The study has examined the following characteristics of the produced coatings: thickness ("Calotest" method, Fischer Sindelfingen device), adhesive strength with respect to the substrate material (Scratch test method), and nano-hardness modulus $E_1$. The tests on nano-indentometer were conducted using a Berkovich indenter with standard methods. For each sample of carbide with produced coating, the nano-hardness was investigated by 25 measurements on area of 100 x 100 $\mu m^2$. Preliminary studies of various properties of coatings allow to select the following NMCC compounds for further research on the basis of compositions TiN (standard arc-PVD technology) and Ti-TiN-(TiCrAl)N; Cr-CrAlN-(NbZrCrAl)N; Zr-ZrN-(ZrNbCrAl)N (FCVAD).

*Methods for study of cutting properties.*

The study has been focused on the steels used in dry longitudinal turning of heavy power engineering. The effectiveness of machining of steels was evaluated by the results of studies of cutting contact characteristics, wear resistance and lifetime of the cutting tool. Cutters with mechanical fastening of cutting inserts (CI) made of carbide grade TT10K8B with square shape (SNUN ISO 1832:2012) were used, with the following values of the geometric parameters of the cutting part: $\gamma = -8°$; $\alpha = 6°$; $k = 45°$; $\lambda = 0$; $r = 0.8$ mm.

The cutting properties of the tool were tested on a universal turning machine 16K20 with a three-component dynamometer and thyristor drive, providing infinitely variable regulation of spindle rotation speed and thus maintaining the desired cutting speed for different values of the diameter of the workpiece. Flank wear land $VB_c$ = 0.45...0.5 mm was taken as a failure criteria. It was measured with toolmaker's microscope MBS-10 as the arithmetic mean of four to five tests.

## 4. Test results and discussion

Figure 1 shows a SEM-picture of NMCC based on the system Cr-CrAlN-(NbZrCrAl)N, with a three-component architecture and nanoscale structure of wear resistant layer, deposited on the carbide substrate TT10K8B (as example).

Thicknesses of the adhesive Cr and transition CrAlN layers of NMCC are 1500 nm and 500 nm, respectively, and sizes of their grains do not exceed 5-15 nm. The use of the vacuum arc FCVAD system allows indicating a considerable improvement of the quality of NMCC layers and almost complete absence of surface micro droplets, which are a dangerous defect of NMCC, since they drastically increase the strength of adhesion between the NMCC and the material being machined, as well as the rate of adhesive-fatigue tool wear [10].

The HPC results of CI with NMCC Cr-CrAlN-(NbZrCrAl)N tested for oxidation resistance in air at heating within the temperature range of 700, 800, 900 and 1000 °C showed their high heat resistance. It was found out that during heating within the temperature range of 700-900 °C, CI was oxidized slightly. In particular, the weight gain for the sample of TT10K8B-(Cr-CrAlN-(NbZrCrAl)N) did not exceed 0.1 $g/m^2$ for 1.5 hours of oxidation in air.