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”LUCIAN BLAGA” UNIVERSITY OF SIBIU
FACULTY OF ENGINEERING

STUDY OF THE GRINDING PROCESS ON METAL CARBIDE CUTTING TOOLS FOR THE MACHINING OF DEEP HOLES

- THESIS SUMMARY -

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The public defense of the doctoral thesis will take place at ”Lucian Blaga” University of Sibiu, Academic Reunion Center, str. Banatului, no. 6, room 11 (ground floor), on 29.04.2016, at 11:00 AM.

Preface

The industrial development, the constant updating of technological equipment, the automatization and computerization of manufacturing systems have led to increasingly intense research in mechanical processing.

As a professor involved in vocational and technical education, I was concerned with the vocational improvement of students in order to train competitive specialists for the labor market. In this respect, I kept in touch with the industrial field, with university professors to be up to date with novelty in this area of study and, at the same time, I noticed that producers in the mechanical domain want to optimize and improve manufacturing processes.

New materials that have not been explored to their full capacity, especially metal carbides used in manufacturing advanced cutting tools and their related technological manufacturing processes, require constant research.

Thus, grinding processing is no longer just a finishing operation but the means through which metal carbides are processed. The complexity of grinding processing gives way to a wide spectrum of research lines.

For this reason, I chose to study the grinding processing of metal carbides, with applications in the manufacturing of drills for deep holes of small diameters that require certain features, a high quality of active surfaces and resistance to different types of wear respectively.

Thanks to my scientific advisor, **Mr. Eng. Paul-Dan Brîndașu PhD.**, I have succeeded to create this present PhD thesis that represents the result of a competent and highly professional guidance.

I would especially like to extend my deep consideration and respect for the way he has supported me all through my research period. Also, I would like to thank him for the understanding and elegance he has extended in order to help me overcome certain problems that have appeared during the scientific research program.

I hereby thank and would like to acknowledge the staff of professors from the Faculty of Engineering for their professional excellence and for their involvement in my training within the PhD program, for their suggestions and recommendations.

I would like to thank the following professors: **Eng. Petru BERCE PhD.**, **Eng. Marian BORZAN PhD.**, **Eng. Nicolae COFARU PhD.**, as scientific reviewers, who had the good will and patience to analyze and evaluate this paper.

I would like to thank **my family** for the support, understanding and patience they have demonstrated during the PhD program.

CONTENT

CHAPTER 5 MONOBLOC CUTTING TOOLS FOR PROCESSING DEEP HOLES OF A SMALL DIAMETER

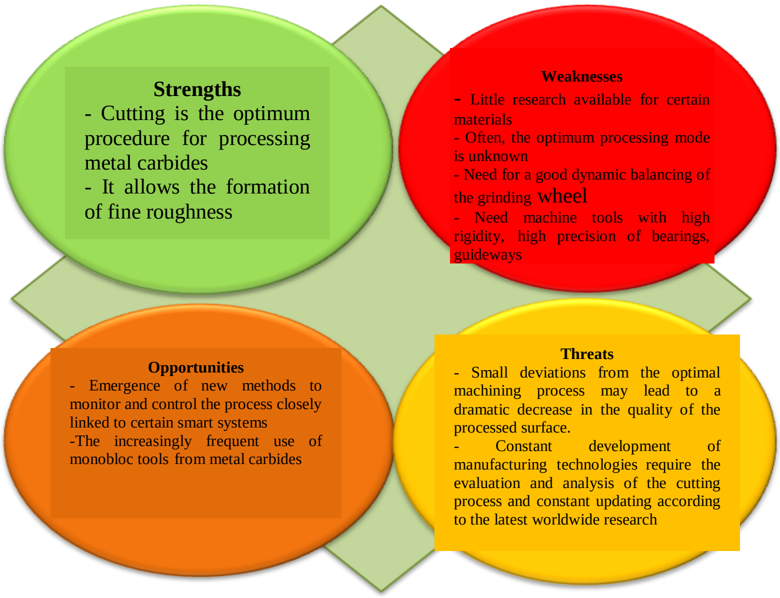
1. INTRODUCTION

Among the cutting processing operations, grinding processing has become the most utilized finishing procedure, reprezenting almost 70% in the spectrum of finishing processing. Nowadays, following the development of technologica equipment and the emergence of new materials, grinding is no longer just a finishing operation.

Grinding, as the main processing operation of metal carbides, has become a field open to current research. The quality of the grinding machining process is reflected in the quality of obtained surfaces, in productivity and production time, but also in costs. The inclusion of grinding in the spectrum of basic processing has led to a need for field research. The grinding process in its entirety is still insufficiently explored.

There are many factors that influence the grinding process, that is why the optimization of the grinding process is an issue open to discussion.

The choice of subject of the present thesis was made after comprehensive bibliographic analysis of research in the field, finding works which have narrowly approached grinding processing of metal carbides with a high content of wolfram, as is the case of the material that is here subject of research, DK460UF, used in manufacturing drills for deep holes with small diameters. The figure below shows the SWOT analysis conducted in order to identify the research opportunities.



Strengths

- Cutting is the optimum procedure for processing metal carbides
- It allows the formation of fine roughness

Weaknesses

- Little research available for certain materials
- Often, the optimum processing mode is unknown
- Need for a good dynamic balancing of the grinding wheel
- Need machine tools with high rigidity, high precision of bearings, guideways

Opportunities

- Emergence of new methods to monitor and control the process closely linked to certain smart systems
-The increasingly frequent use of monobloc tools from metal carbides

Threats

- Small deviations from the optimal machining process may lead to a dramatic decrease in the quality of the processed surface.
- Constant development of manufacturing technologies require the evaluation and analysis of the cutting process and constant updating according to the latest worldwide research

The present doctoral thesis approaches a small part of the issue of the grinding processing of metal carbides and the grinding of metal carbides for manufacturing drills for deep holes of small diameters respectively. During the present research process, the main issues tackled were identifying the optimal processing parameters for grinding the DK460UF metal carbide, in order to obtain a surface of high dimensional precision, with a low level of roughness and with an adequate appearance (no oxidation, burns).

The paper is structured on 7 chapters presented in the following paragraph:

Chapter I contains a short history of machine tools used in cutting processing, the timely evolution of cutting machines and tools, as well as the evolution of materials used in manufacturing cutting tools and current trends in the manufacturing of these tools.

Chapter II presents the theoretical aspects of the grinding process (the features of the grinding wheel, the kinematics of the grinding process, the cutting mode, the grinding forces, the wear of the grinding wheel) and the current state of studies performed by different researchers regarding the grinding processing of various materials, the properties of the grinding wheel and phenomena that accompany the grinding process.

Chapter III contains the objectives of the doctoral thesis and the research methods employed.

Chapter IV deals with the modelling of the grinding process. An overview of process modelling and models of the grinding process from the scientific literature are presented. Also in this chapter, the issues of the grinding process of metal carbides are approached, mentioning the main specific aspects. Taking into account the multitude of factors that influence the quality of the machining process, it is necessary to rank them. The studied models, as well as the main influencing factors that are identified, have created the basis for establishing a general model for grinding metal carbides with a high content of WC. A crucial factor in performing the grinding process is temperature. The flow of temperature affects the quality of the processed surface. That is why it was necessary to create a numeric model for the temperature flow to investigate the heat transfer in the contact area between the grinding wheel and the processed surface, required to create a comparative study with experimental research.

Chapter V includes the technological process of grinding using numerically controlled machine tools for metal carbides in order to obtain deep hole drills. In this chapter, the algorithm for planning the technological process for machining deep hole drills is presented, as well as the manner of selecting the cutting tool from the tool storehouse of the machine tool, using specialized software to design, visualize and simulate the processing technology, such as: TOOLdefine, SolidPRO, 3D-Collision.

Chapter VI is dedicated to experimental research. The methodology for experimental research and the Design Expert software used for determining the mathematical models of researched factors, as well as for graphically representing the variation of investigated parameters in relation to the independent variables considered. To obtain an overview on studies performed, a model for experimental research was elaborated. The cutting mode, the properties of the grinding wheel and the features of the processed materials are considered to be independent variables and the grinding force, temperature, wear of the grinding wheel and roughness of the processed surface are considered to be dependent variables. The level of variation for each parameter of the cutting mode was established and the grinding wheels for processing were selected. The experiment was planned for each output parameter under study and the data required for their mathematical modelling were acquired. The analysis of the obtained models was conducted using the ANOVA statistical analysis. The conclusions resulting from the study of the dependency of processed surface quality on the processing elements taken into account have led to the establishment of optimal parameters for processing DK460UF metal carbide, with a 91% WC content and 9% Co content.

Thus, for the study of grinding forces, processes on plane grinders with two grinding wheels of different diameters were performed using different cutting modes. To measure the components of the grinding force, the tangent and normal forces, the KIESTLER dynamometer was used. This dynamometer uses DynoWare software, which enables the recording of measured values and the export of data in Microsoft EXCEL, where these data can be processed. The values obtained were used in building the program matrix required to obtain the mathematical model.

In measuring temperature, a metal carbide - enamelled copper thermocouple was used, and a type K (Chromel - Alumel) thermocouple was used as calibrator. A stand for the calibration of the metal carbide - enamelled copper thermocouple was used. This thermocouple was then used in measuring the temperature in the processing of DK460UF metal carbide, on a plane grinder. The processing was performed at different cutting modes. To visualize the intensity of temperature flow in the contact area, INFRARED CAMERAS were used.

The wear of the grinding wheel was monitored in processing drills for deep holes with diameters between 2.025 and 2.5 mm. The wear of the profile was monitored on samples with 100 benchmarks, until catastrophic wear occured. The evaluation of the wear was performed using the Walter Helicheck Basic Optical CNC measuring machine. Comparative tests were performed regarding the variation of wear in wheels with different grits, in relation to the volume of removed material. These results were used in studying the G-ratio, parameter which defines the efficiency of the grinding process.

The roughness level was measured with MITUTOYO roughness tester. The processing of samples was performed on a numerically controlled CNC HAWEMAT 3000 machine, with different cutting modes, with grinding wheels of 46 µm and 54 µm grit, new and used. The quality of the processed surface was studied using the values of measured roughness and the appearance of the surfaces was examined using an electronic microscope at the French Institute of Advanced Mechanics of Clermont Ferrand, France. The defects determined by the degree of wear in the grinding wheels were emphasized.

The results of experimental research have led to the establishment of grinding parameters for an optimal machining process.

Chapter VII includes the general conclusions related to the entire research and the original contributions in approaching the subject of the doctoral thesis, as well as future research lines.

1. SHORT HISTORY OF CUTTING. CURRENT TRENDS

This chapter revisits certain important stages in the evolution of machine-tools, cutting tools and materials used in manufacturing them. With the evolution of machine tools and cutting tools, the theory of cutting was gradually developed.

1.1. Overview

The evolution of cutting is linked, during its whole evolutionary period, on the evolution of cutting tools and of machine tools, their interdependence leading to progress in each of these three fields, a development in one automatically leading to progress in the other fields.

1.2. The evolution of machine tools

Machine tools have a long period of evolution, from the lathe with wooden frame to the numerically controlled machines.

Lathe wood machine frame [72] **Lathe function by pedals [72]**

Lathe close to that of today [72] **Lathe latest generation [72]**

Fig. 1.1. The evolution of the lathe

1.3. The evolution of cutting tools

The cutting tool is part of the technological equipment that, according to the kinematics of the machine tool, divides the tooling allowance and it removes it as chips in order to obtain the shape, size and smoothness of the workpiece surfaces.

Primitive tools were created entirely out of carved stone, using different techniques, with different cutting angles.

Fig. 1.2. Primitive tools [228]

Figure 1.3. presents the evolution of the cutting tool with its most important developmental stages.

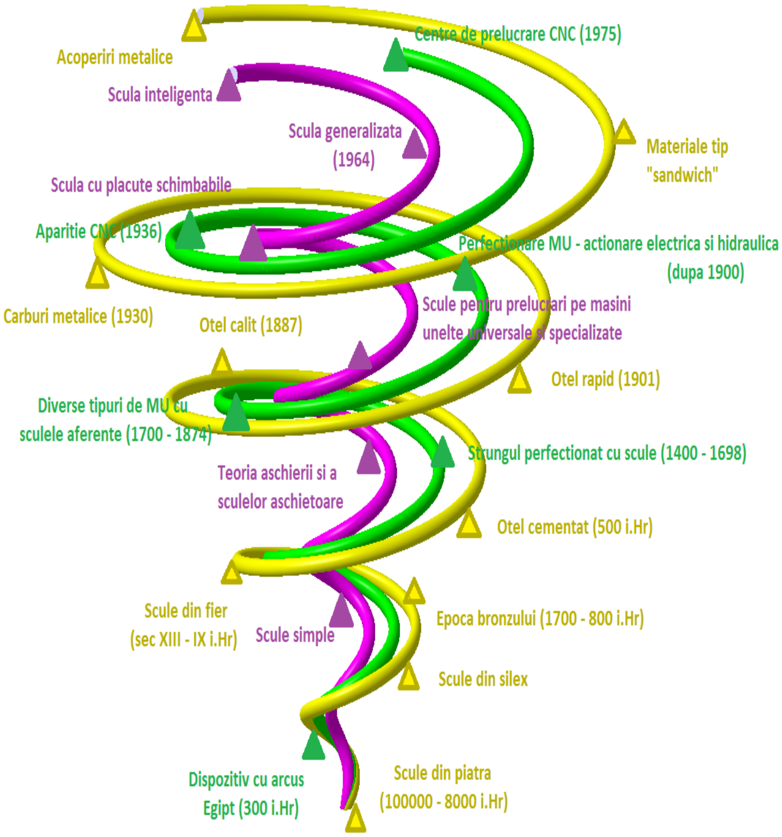


Fig. 1.3. The evolution of the cutting tool and its developmental stages. [138]

Performances in manufacturing cutting tools have influenced the evolution of technological processes and the construction of machine tools, in order to improve the process parameters.

A series of trends were observed in the development of cutting tools:

- The improvement of cutting power through new tool shapes with blades made of advanced materials
- Replacing monobloc tools with tools that use advanced materials only in the active part
- The gradual replacement of mono-blade tools with tools that have multiple blades
- Fast reconditioning using changeable plates
- Increasing the precision of manufacturing tools by using computer-aided design.

2. THE CURRENT RESEARCH STATUS REGARDING THE GRINDING PROCESSING OF METAL CARBIDES

In this chapter, the grinding process is described in its entirety in order to identify the factors that govern the process and their interdependence.

2.1. Theoretical aspects of grinding processing

The grinding process is analyzed according to:

- the grinding wheel (the nature of granules, grit, binder, hardness, factors that influence the choice of a grinding wheel);
- process kinematics (movements, forces, chip removal mechanism);
- the cutting regime (speed, feed, depth of cut);
- the cutting medium (properties, types of cooling liquids);
- the vibrations;
- the wear of the grinding wheel (the factors and the influence of wear on the process);
- the quantity of heat generated during the process (heat generated during the interaction between the grinding granule and the surface to be machined, the distribution of heat between the grinding wheel, the surface to be machined, the chip and the cooling medium, methods to reduce the temperature in the contact area, the variation of heat quantity in relation to the process parameters).

2.1.1. Materials used in building grinding bodies

Grinding bodies have three main components: abrasive granules, binder and pores, according to figure 2.1., each with its well-defined role [24].

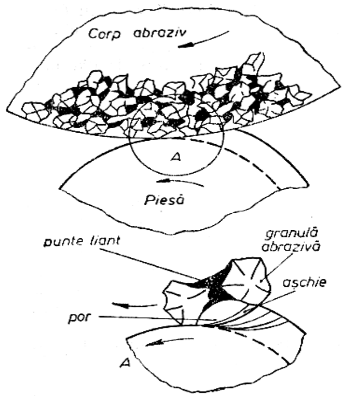


Fig. 2.1. Grinding wheel [24]

The main grinding materials used in constructing grinding bodies are: the elctrocorundum, silicon carbide, boron carbide, cubic boron nitride and diamond.

2.1.2. Features of grinding bodies

Grit characterizes the size of the abrasive granule and is measured in µm.

Hardness of grinding bodies represents the resistance of the binder to the avulsion of the granule.

The structure of a grinding body represents the percentage ratio between the volumes of abrasive granules, of the binder and the pores.

The binder is made of a softer material than the granules and is mechanically and thermically manipulated. The most frequently used binder is the ceramic one, followed by synthetic resin mineral, organic and metal binders [180].

2.1.3. Selecting the grinding bodies

The selection is performed according to: the material of the abrasive granule, grit, hardness and the influence of the contact area between the workpiece and the grinding body.

2.1.4. The kinematics of the grinding process

The kinematics of the grinding process includes movements that generate the processed surface, the path described by the cutting tool, in order to remove the chip, the chip removal mechanism and the chip formation respectively.

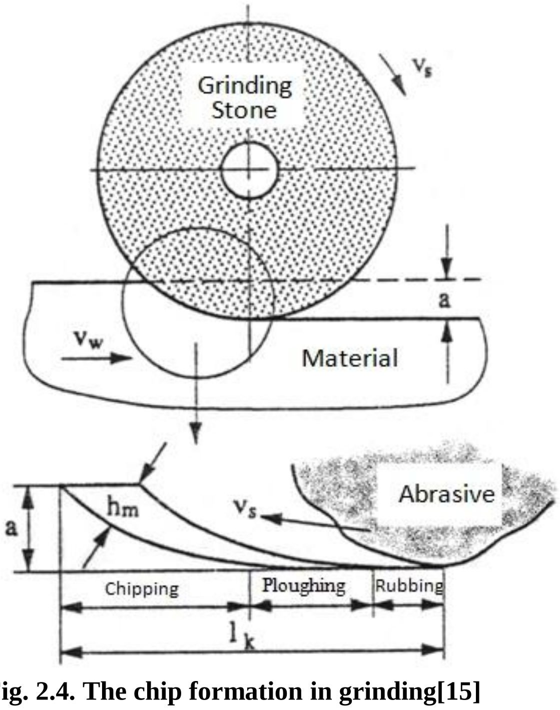


Fig. 2.4. The chip formation in grinding[15]

According to the depth of the cut, the grain goes through three stages of chip formation: sliding, ploughing and cutting. The importance of the three stages is relative to the position of the granule on the surface of the wheel and on the kinematics of processing.

2.1.5. Cutting forces

The cutting forces may be estimated taking into account the interactions of granules that pass through the grinding area. (fig. 2.5.)

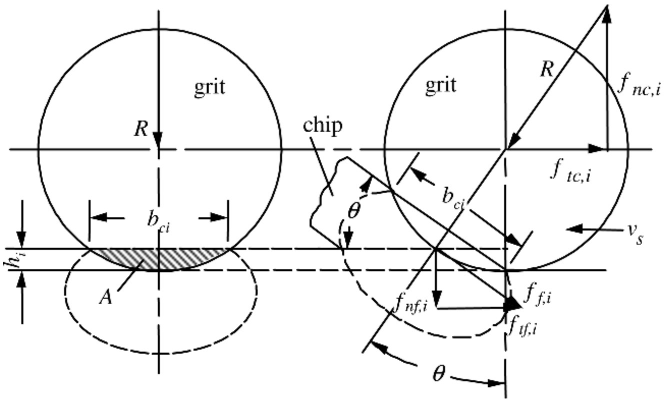


Fig. 2.5. Cutting force for an abrasive granule- *$f_{f,i}$ - friction force; $f_{nf,i}$- normal friction force; $f_{tf,i}$ - tangent friction force; b_c - the length of the contact strip; h - the width of the contact strip* **[36]**

The cutting forces in the grinding process have two main components, the normal component and the tangent component, F_n and F_t. (fig. 2.7.)

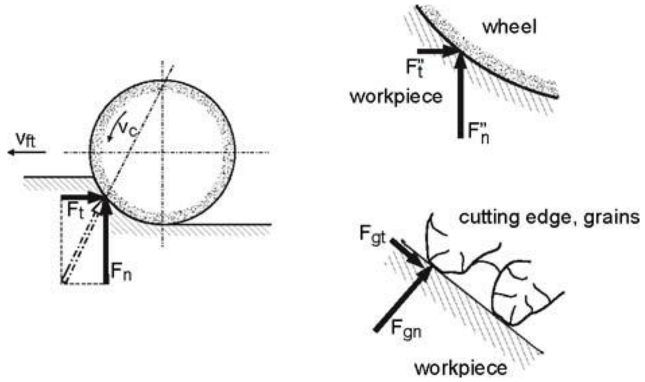


Fig. 2.7. Components of the cutting force in the grinding process [187]

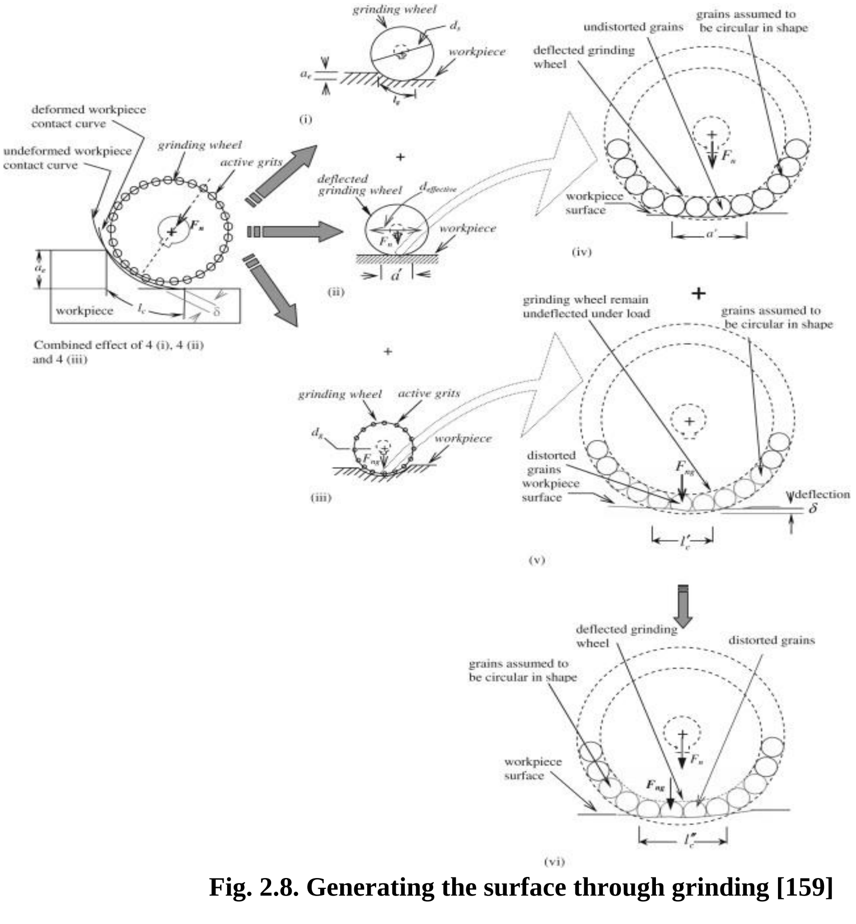


Fig. 2.8. Generating the surface through grinding [159]

In figure 2.8. (i - iii), the real contact length is the result of 3 components: the geometric contact area, the elastic distortion between the wheel and the surface to be processed and the contact between the abrasive granule and the surface.

To calculate the real contact length, the mutual elastic distortion between the grinding wheel and the workpiece to be processed and between the grains and the workpiece will first be considered and then the effect of the depth of cut. [159]

2.1.6. Aspects of the grinding process

Grinding involves a high number of variables that are inter-related. Before processing, it is necessary to decide which variables may be considered in the process of selecting the grinding conditions. The relationships and interactions between these variables are taken into account within the process control system. The dependency relationships between different process parameters is the subject of many papers.

2.1.7. The cutting regime

The speed is the peripheral speed of the grinding wheel in relation to the surface to be processed. It is regularly expressed in m/s.

The feed rate (feed) is defined as the longitudinal movement of the workpiece relative to the axis of the grinding wheel upon its rotation. The feed rate is used in calculating the total processing time. It is measured in mm/stroke or mm/rev.

The depth of cut represents the thickness of the layer of removed material upon one action of the cutting tool on the surface to be processed. It is measured in milimeters. Normally, the depth of cut remains between 0,005 and 0,04 mm. Lower values are assumed for high precision finishing and grinding.

An important parameter defining the accuracy of grinding processing is the rate of material removal, measured in mm^3/s.

2.1.8. The cutting medium

The cutting medium is highly influential in the grinding process, especially in terms of processing with high cutting speeds.

However, considering the undesirable effects it has, such as: environmental pollution, operator discomfort and the harmful effects on health, as well as the costs it involves, a lot of research focuses on lowering the quantity of cooling liquid or even eliminating it (dry grinding).

2.1.9. Vibrations

The vibrations in the grinding process may be external to the grinding process or they can be generated during grinding.

External vibrations are determined by the processing system (machine tool, devices, guides, connecting elements, etc.)

Internal vibrations (related to processing) are determined by the processability of the material, the irregularity of the surface, the modification of material properties during processing, a feed that is too high or too low.

2.1.10. The wear of the grinding wheel

In this paragraph, it is presented the main causes that determine the wear of the grinding wheel.

2.1.11. Quantity of heat in the grinding process

The formation of the chip during grinding processing may be divided into 3 phases:

1. The contact between the abrasive granule and the surface to be processed
2. Elastic distortion
3. Plastic distortion and chip detachment

A great part of the power consumed during grinding is converted into heat. This is due to the sliding and friction of abrasive granules on the processed surface. Friction is accompanied by a large quantity of heat. By decreasing the slide and friction, the temperature also decreases in the contact area. A solution in this case would be to increase the thickness of the chip.[107]

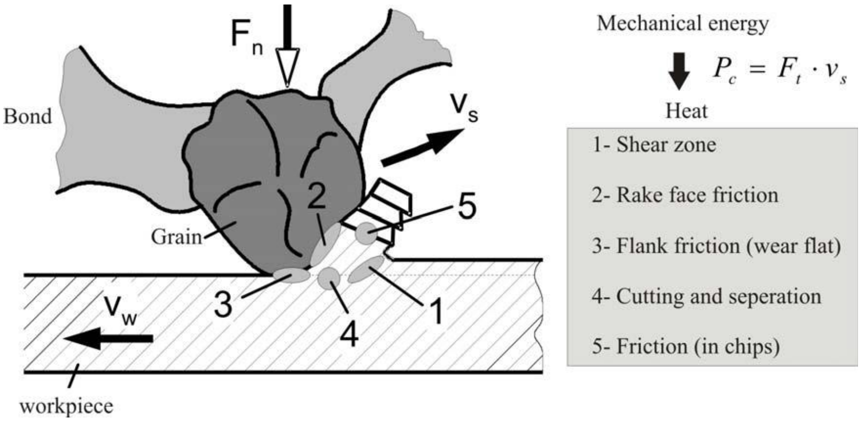


Fig. 2.13. Heat generate in the interaction between the abrasive granule and the workpiece [107]

2.1.11.1. Determining the quantity of heat in the contact area

This paragraph contains the calculation of the heat flow in tha contact area and the maximum temperature dependency of the grinding parameters, such as: speed, speed of piece, depth of cut and the grinding wheel diameter. (fig. 2.21.)

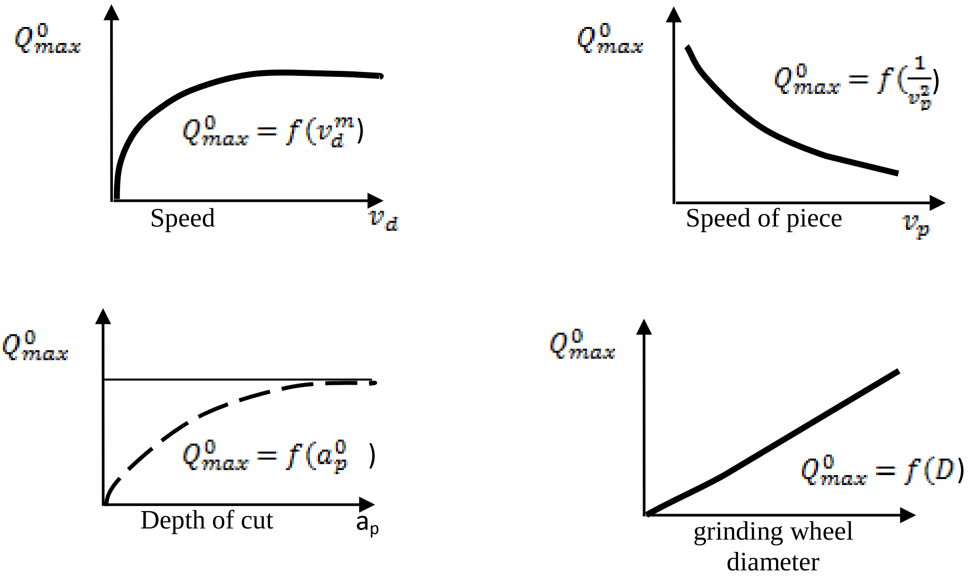


Fig. 2.21. Variation of maximum heat according to the process parameters [227]

2.1.11.2. Methods of decreasing temperature in the grinding process

This section contains a series of research done in order to reduce the temperature in the grinding process.

Decreasing the temperature and its effects require an analysis of thermal aspects, of the distribution of heat.

To decrease heat in the grinding process of metals, the total number of abrasive granules and the number of active granules may be reduced. This may be accomplished through the grinding wheels called T-Tool şi T-Tool profile structured wheels. [42]

T-Tool is an innovative system for discontinuous or intermittent processing. This cutting tool is plane with superabrasive granules on a single layer.(fig. 2.22.)

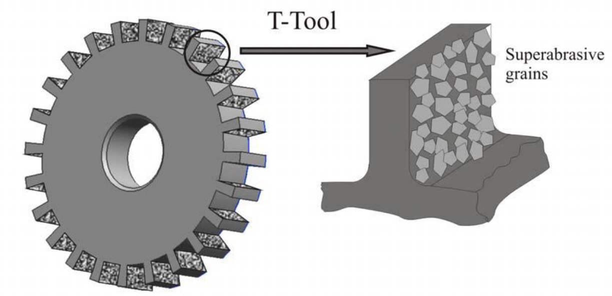


Fig. 2.22. Structured grinding wheel T-Tool [42]

T-Tool can guarantee decreased temperature during processing, the high durability of the cutting tool, the adequate quality of the processed surface.

The first grinding experiments on fragile materials have shown that the T - Tool profile may sometimes reduce the grinding forces with up to 50%, compared to CBN type wheels. [42]

2.2. Research regarding the grinding process

The dense bibliographical research that has been carried out in this chapter is summarized in tables 2.2., 2.3., 2.4.

Table 2.2. Research regarding the grinding processing of different materials

Materials	Authors	Conducted analyses	Conclusions
Titanium Alloy (Ti6Al4V)	Xipeng Xu, Yiqing Yu (2002) [214]	The wear of a grinding wheel with Al_2O_3 carbide granules was compared to the wear of a grinding wheel with CBN granules, produced due to chemical interactions at different temperatures.	It was found that the wear phenomenon is slightly reduced in the case of the cutting wheel with CBN granules due its the chemical stability at high temperatures. Until the study was conducted, the causes were connected to the chemical composition of the material to be processed and of the grinding granules without taking into account the influence that temperature has on this type of wear.
Steel	Sorokin,G. M., Malyshev, V. N (2008) [171]	The dependency relation between the hardness of the material to be processed and the hardness of the grinding granules is analytically determined.	According to the mechanical features of steel, the friction coefficient between the considered grinding wheel and steel is determined, and based on it, the resistance to wear.
BOK60 Ceramic carbide	Ljubodrag Tanovic ş.a. (2011) [181]	Optimizing processing by determining the critical depth of penetration and the normal and	The critical penetration depth ranges between 3 – 5 µm, while the radial fissures on the surface of the

		tangent components of the cutting according to their feed and depth	carbide are distributed at an angle between 35^0 and 75^0 in relation to the direction of movement of the grinding granule. If the speed is increased from 15m/s to 25 m/s, the radial propagation angle of the fissure is 10^0 for the same penetration depth of the granule.
Ni based alloys	Qiang Liu, Xun Chen, Nabil Gindy (2007) [148]	The analysis is based on the Taguchi method by testing the Al_2O_3 grinding wheels and the supergrinding wheels with diamond granules	The performance of the process is represented by the roughness of the processed surface, by the G ratio value, by the processing forces, power and temperature. The process is smoother using supergrinding wheels, the process is run with great cutting forces. In the processing using CBN cutting wheels, water should not be used as a cooling liquid.
	Stefan Olovsjö ş.a. (2010) [137]	Dependency between hardness and the size of cutting wheels employed has been established	The size of grinding granules and the thickness of undistorted chips influence the behavior of the material upon processing. The wear increases with the increase of hardness and the size of granules does not affect the wear of the flanks.
Brittle materials	Z. W. Zhong &V. C. Venkatesh (2009)	Two grinding modes were compared, parallel grinding and cross grinding.	The critical depth of cut of the brittle materials is determined according to the critical thickness of the chip for a given mode.
Steels and alloys with high plasticity	L. V. Khudobin and A. N. Unyanin (2008)	Reducing the wear of the grinding wheel due to the adherence of metals to its surface by determining the forces connecting the metal particles and the wheel's surface.	Methods have been found that can be used for cleaning the surface of the grinding wheel, using lubrification and cooling liquid under a pressure jet, cleaning hydraulically and mechanically using a grinding bar.

Table 2.3. Research on the properties of the grinding wheel

Analysis of the grinding wheel	**Authors**	**Conducted analyses**	**Conclusions**
Correlation of binder – grinding grains – grinding capacity	Hitoshi O., Masaki K., s.a. (2007) [71]	The experiments were conducted on 6 grinding wheels, using powders of iron (3,11% C), of steel with 0,02%C and with 0,01%C. In the binder matrix, the number of diamond grinding granules is between 325 and 1000. The ratios between the processing time and the volume of material removed were determined for the 6 grinding wheels with different structural features, as well as the ratio between the grinding pressure and the volume of material removed. The grinding capacity was evaluated using the method of processing a Al_2O_3 – TiC metal carbide with	The hardness of the binder material is essential in avoiding the plastic distortion of the grinding wheels. When using fine grinding granules, the binder hardness is important to ensure o greater grinding capacity than in the case of grinding wheels with gross grinding granules. When grinding Al_2O_3 – TiC, the porous grinding wheels with a metal binder have a grinding capacity two times greater than those with another type of binder, with grinding granules of the

		constant pressure. The roughness of the binder, the connecting forces between the diamond grinding granules and the binder materials and the porosity of the wheel are relevant in determining the grinding capacity.	same size. Porous wheels are easier to calibrate and repair.
The shape of the grinding wheel surface for processing involute cylindrical tools	Stephen P. Radzevich, Radoslav Krehel (2012)[150]	The profile of the grinding wheel is determined based on the differential geometry of surfaces and on the kinematics of movement for a solid in a Euclidian space. The SHAVER software is used to analytically determine the surface and then the theoretical surface is superimposed on the real surface, using CNC with 9 axes. The consecutive positions of the wheel in rotation are observed and the contact with the processing surface is made along a line.	The shape of the grinding wheel surface is determined using the method of discreetly processing the specified surfaces, method which allows the identification of the discreetly defined wheel's shape and features. The analytical method is embedded in SHAVER that can be used in profiling the wheels needed to shape the involute tools. Differential geometry for defining surfaces to be processed is employed as mathematical support.
Grinding grains of transition metal carbides	A.A. Adamovskii (2007) [1]	A classification of 3 groups has been created for each type of crystal granules according to the shape of the surface and the material. Gr. I – classic grinding granules with flat crystal surfaces, widely applied. Characterized by intra- and intercrystalline fissuring that determines the self-sharpening of grinding granules. Gr. II – lightweight granules, with low mechanical resistance. Used in finishing and trimming. They disintegrate intensely in the machining process. The surface is of low quality. Gr. III – granules with sintered structure used in the roughing process. The performance of the grinding wheel depends on the material and the structure of the granule.	Transition metal carbides have high processing properties upon grinding. The processing operation is efficient and the quality of the surface that is processed is high. The borides, carbides and nitrides of transition metals solve part of the inconveniences of other grinding materials (elasticity, thermic conductivity, chemical activity). Sintered grinding materials based on the carbides of transition metals were researched especially from the point of view of their behavior upon sharpening the grinding tools.
Topography of the grinding wheel	Fengwei HUO, Zhuji JIN, ş.a. (2008) [75]	To investigate the grinding process, it is necessary to accurately evaluate the topography of the grinding wheel. For this purpose, the distribution of diamond granules was analyzed, as well as their profile and the distance between the two adjacent granules. The interferometry of white light is employed on the surface of the wheel, measuring in 3D.	To recognize the diamond granules, it is necessary to sample a small space interval on a large reference surface with a strong resolution. The white light interferometry is efficiently used to measure the surfaces of grinding wheels with fine granules. The method based on the occurrence frequency of granule profile features and the distance between 2 adjacent diamond granules is used to identify the diamond granules.
Active grains	Safonova M.N., A.S. Syromyatnikova, ş.a.	Research has been conducted to elaborate a methodology for determining the number of active grinding granules through methods of	The presented method may be applied in evaluating the granule concentration of random shapes and statistically homogenous

	(2007) [156]	experimental calculation. The algorithm of this method consists of choosing the geometric model of the active granule, the calculation of the number of active granules in the composite material and the verification of obtained results. To choose the geometric model, a parameter that characterizes the deviation of the real volume of grinding granules from the analogue model has been established for different geometrical shapes of the granules. To determine the quantity of active granules, the method of *quantitative metallography* was used. The number of particles was established using the probabilistic distribution for cubic particles. The verification of results was don through the so-called *CDS method* (Computer Diagnostic Sieve)	distribution in relation to the volume of composite material. The cutting process is intensified in relation to the increase of the granule size. This is due to the increase of stress on the granule that leads to the decrease in the binder's power to retain grinding particles.
Distribution of grains on the work surface of a grinding wheel	V.A. Nosenko, E.V. Fedotov, ş.a. (2007) [130]	Considering that not all granules take part in the machining process, a probabilistic model was created on the work surface of the grinding wheel, taking into account the probability of contact between the grinding granule and the processed surface and different types of wear that may occur. The wears that occur are: grinding wear, the avulsion of granules from the binder matrix and wear as a result of chemical reactions. To elaborate the probabilistic model, it is necessary to know the probability of occurrence for each type of wear of the grinding granule and its size. Three grinding wheels may be used if the three types of wear occur, or the work surface of a wheel is divided radially into three sections.	The work surface of the grinding wheel is seen as a probabilistic system that includes three subsystem: the contact probability of the granules with the processed surface, the probability of granule wear and the transition of probabilities according to the modifications of the granule state, as a result of the wear.
Grinding grains of different sizes	G.A. Guseinov, S.A. Bagirov (2009) [63]	The subject of the research was to improve the grinding process by ensuring the uniform action of grinding granules on the surfaces to be processed. It is known that once the grinding granules decrease in size, their number increases and the processed surface roughness also decreases. A grinding wheel with strips that contain grinding granules of different sizes is analyzed, in order to ensure a uniform action. The size of the granules and the grit are determined.	Based on the employed method, granules of a large size are chosen for the front of the strip that decrease in size if the strips are consecutive (their number increases with their decrease in size). It has been demonstrated that if granules act in a uniform fashion in the grinding process, their number is reduced: external friction and temperature and the efficiency of the grinding process increases.
Comparison between the surfaces of standard grinding	S.A. Bagirov (2012) [11]	It has been theoretically proven that the grinding granules from consecutive strips of grinding wheels act in a uniform fashion (G.A.	Two mathematical models are obtained, which are statistically and experimentally analyzed from the point of view of the

wheels and those with grinding grains of different sizes		Guseinov, S.A. Bagirov (2009)). In the present study, these suppositions are verified and the dependency of the processed surface roughness on the grinding conditions imposed by the two types of grinding wheels is determined.	processing parameters. The roughness of the surface processed with the two types of grinding wheels is measured. The obtained models allow the optimization of the processing parameters of the grinding wheel with different grinding granules. The analysis of results shows that the roughness of the processed surface is considerably lower in the case of processing using wheels with consecutive strips than in the case of standard wheels.

Tabelul 2.4. Research on the grinding process

Influence factors	Authors	Performed analyses	Conclusions
Cutting forces	Qiang Liu, ş.a. (2007)	The cutting forces were analyzed as important factors in the grinding performance. The cutting force results from the normal and tangent component. These components were studied in comparison on two Al_2O_3 and CBN wheels.	The cutting forces are smaller on CBN wheels and greater on Al_2O_3 wheels, but the roughness is greater because the friction wear and tear of the CBN grinding wheel is greater upon roughing, the temperature is higher and leads a the reaction between CBN and the water-based cooling liquid.
Friction forces (friction coefficient)	G. M. Sorokin and V. N. Malyshev (2008) [171]	The friction coefficient is calculated in the absence of the lubricant using a bar type wheel. The dependency between the friction coefficient and the features of the material (plasticity, yield strength, resistance to wear) is analyzed.	It has been observed that with the increase of the resistance and hardness of the material, the friction coefficient decreases. An increase in plasticity leads to an increase of the friction coefficient. In the grinding process without lubricant, the friction coefficient influences the wear rate of the wheel.
Generated heat	K. Salonitis, ş.a. (2008)	The generated heat is the result of the plastic distortion of the material to be processed, as well as of the friction between the processed surface and the surface of the grinding wheel. In the study conducted, the heat generated due to plastic distortion is neglected and the research focuses on the heat generated through friction.	The study focused on the evaluation of the influence that the grinding wheel features exert in the process of grinding hard materials. A model for estimating the quantity of generated heat in the grinding process was conceived, as a function of the process parameters and the features of the grinding wheel. The dependency of the Hardness Penetration Depth (HPD) on the process parameters was experimentally determined. HPD is the depth at which hardness is reduced with 80% in relation to the nominal value.
	Xipeng Xu, Yiqing Yu (2002) [214]	The processing temperature in the contact area creates structural modifications of the processing surface, as does the adherence of the	The study was conducted to determine the factors that increase the lifespan of a cutting wheel and to correlate the structure of the cutting wheel with the quantity of heat

		material to the surface of the grinding wheel. The behavior of a grinding wheel with Al_2O_3 granules and of a supergrinding CBN wheel were analyzed.	gemerated in the grinding process. At different processing temperatures, 450^{0}C, 800^{0}C and 1000^{0}C, it has been found that the supergrinding wheel has better chemical stability and greater resistance at higher temperatures.
	A.V. Repko, V.A. Smirnov (2008) [152]	Alloys of low thermal conductivity have processing defects because of the temperature in the contact area. The density of the flow of the heat absorbed by the material to be processed depends on the cutting speed, on the tangent component of the cutting force. At a constant processing speed, thermal defects occur due to the sudden increase of the cutting force. The decrease in thermal tensions may be accomplished by applying a grinding process with discontinuous grinding wheels with elastic elements.	The analyzed discontinuous wheels have elastic elements fixed on their surface to decrease the contact area.
Cooling fluids	Mamun A. A., Dhar N. R. (2012) [118]	The decrease in the quantity of cooling liquid is aimed at and its influence on the way of shaping the chip is evaluated, as well as the roughness of the surface processed with Al_2O_3 and CBN grinding wheels at different levels of the processing parameters in a dry medium, as well as in the case of a minimum quantity of liquid.	An analytical model of the processed surface is developed based on experimental investigations, which demonstrate that the roughness of the processed surface is significantly lower when a cooling liquid is used compared to a dry medium. The roughness is proportional to the rotation speed of the grinding wheel. The work speed significantly influences the value of the roughness. CBN wheels are more stable than the conventional ones. The model obtained may be used with a 96,46% accuracy to evaluate the roughness of the processed surface.
	Tawakoli T., Westkaemper E. (2007) [186]	Dry grinding (without cooling liquid) is an economic and ecological process, but it is hard to employ due to the nature of the grinding process. The cooling liquid is used to reduce and eliminate the heat generated during the process. The heat reduction may also be performed by modifying certain parameters connected to the cutting mode and the structure of the grinding wheel.	The study is based on identifying certain strategies to minimize the use of fluid. The strategies employed fall into 3 main groups: I. The transfer of heat between the surface to be processed and the grinding wheel is performed through another medium. II. The transfer of heat is oriented towards the grinding wheel or the formed chips, so that the processed surface is not affected. III. The transfer of heat is closely linked to the way in which the chip is shaped, which represents the subject of the study. The research is focused

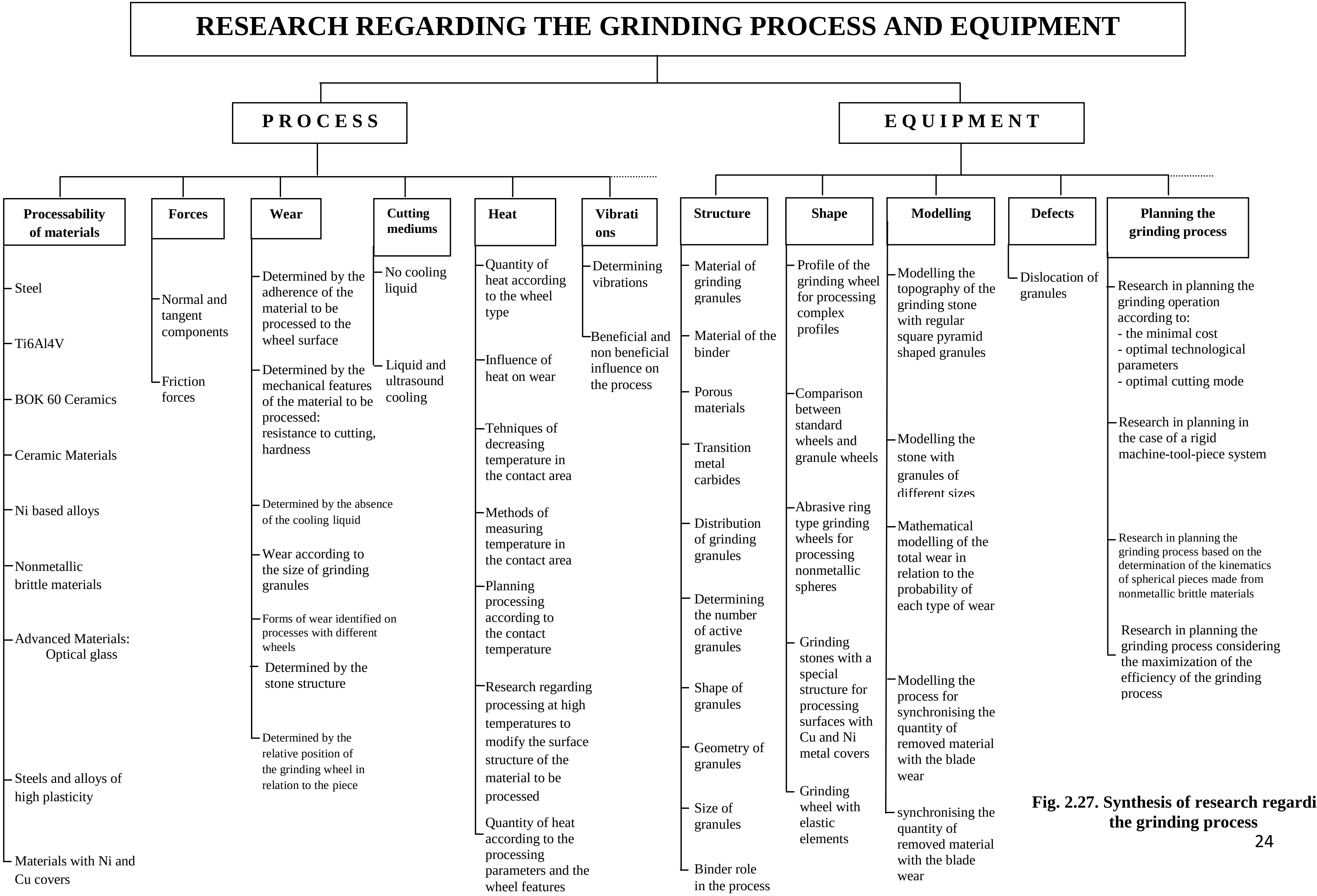
			on optimizing the shaping of the chip. Any modification in the parameters of the grinding process has an influence on the quantity of heat generated in the process. In this study, the efficiency of processing is determined by the increase of the execution time.
Vibrations	Yao Yan, Jian Xu (2012) [217]	Vibrations that accompany the grinding process have an effect on the wear of the grinding wheel and the quality of the processed surface. The dynamic behavior of the grinding wheel system - workpiece in cylindrical grinding - is analyzed in this study. The relation between the contact force and the rotation speed of the piece and the grinding wheel is determined. Finally, the areas in which there are no vibrations or in which the values of vibrations are insignificant are identified.	The mechanism through which the contact force induces vibrations is clarified by combining the analysis of its own values with the alrgorithm for continuity. To avoid vibrations, the contact force can be decreased by using a soft grinding tool of a small width, or by reducing the feed speed. To design a grinding process, a linear and non-linear analysis of the phenomenon is necessary.
Efficiency of the grinding process	Wang S., C.H. Li (2012) [200]	The current state of research regarding the efficiency of the grinding process in relation to the process factors, high feed, great depth of cut, as well as the machine – piece – grinding wheel system are presented.	The issues that are physically and chemically specific to the grinding process are identified and the research lines are established for each identified issue regarding the increase of performance as well as the reduction of costs for advanced material processing.
The wear of the grinding wheel	Feng Z., Chen X. (2007) [53]	The study is based on the use of image processing tools in MATLAB to determine the degree of wear in the grinding granules.	The uses of these image processing techniques are efficient in identifying the stress on the wheel and for monitoring the grinding wheel in real processing situations.
	Sumaiya Islam, Raafat N. Ibrahim (2011)	The cutting wear through friction is studied in two parts, the attack on the processing surface and the cutting process itself.	The friction coefficient is determined for the processing with two types of grinding wheels according to the parameters of the cutting mode.
The rigidity of the processing system	V.I. Lavrinenko (2009)	The study takes into account the rigidity of the grinding wheel as an influencing factor on process performance. The rigidity of the machine – tool – piece system is determined by each component of the system. A comparison between the rigidity of the cutting wheel and that of the other components is performed. Research aimed at clarifying the dependency between the	It has been demonstrated that when the rigidity of the grinding wheel is much greater than that of the equipment, it does not affect the process performance. If the system of the machine has an inadequate rigidity, it can be compensated by reducing the forces in the cutting process. Standard profile grinding wheels are of great rigidity. Even if we were to reduce this feature threefolds it would not significantly affect the process performance. A value of 10 MN/m may be considered a rigidity limit for

		wear of the grinding wheel and the roughness of the surface in relation to the axial rigidity of the wheel. Tests have been performed on the processing of T15K6 carbide. The way in which the rigidity of the grinding wheel may be controlled was discussed. The factors that influence rigidity have been identified: the thickness of the wheel, the elasticity module and the diameter.	the grinding wheels, as well as for the grinding machine.
Designing the grinding process	Koshin A.A., Chaplygin B.A. (2011) [97]	The technological process must satisfy the requests of the client regarding the product delivery time and the minimal costs|.	The process optimization is done by creating certain mathematical models that reflect the dependency between the features of the process and those of the grinding wheel in processes with different wheels under different cutting conditions.

2.3. Conclusions

The documentation activity has led to the identification of these lines of research that do not present enough information, or that do not lead to the best theoretical and experimental results. The forementioned analysis has resulted in the following conclusions:

- The grinding process is a complex process that depends on a multitude of variables;
- The processing of hard materials is performed only by grinding;
- The factors that have the greatest influence on the quality of the processed surface by grinding are: the grinding wheel, through its shape, properties and degree of wear, the parameters of the cutting mode, the cutting speed, the feed speed, the depth of cutting.
- The grinding process has the following advantages: high precission, high quality of the surface, high productivity;
- In the presented experimental analyses of the grinding process, materials of titan alloy type, alloys based on nickel, brittle materials, steels and alloys of high plasticity were taken into consideration and metal carbides with a high content of wolfram carbide were less analyzed;
- No studies were conducted regarding the grinding of small surfaces, with edges and holes, such as the active surfaces of drills for deep holes of small diameters
- The modelling and simulation of the grinding process was elaborated in general, even less for the situation that was formerly presented.



RESEARCH REGARDING THE GRINDING PROCESS AND EQUIPMENT

- **PROCESS**
  - **Processability of materials**
    - Steel
    - Ti6Al4V
    - BOK 60 Ceramics
    - Ceramic Materials
    - Ni based alloys
    - Nonmetallic brittle materials
    - Advanced Materials: Optical glass
    - Steels and alloys of high plasticity
    - Materials with Ni and Cu covers
  - **Forces**
    - Normal and tangent components
    - Friction forces
  - **Wear**
    - Determined by the adherence of the material to be processed to the wheel surface
    - Determined by the mechanical features of the material to be processed: resistance to cutting, hardness
    - Determined by the absence of the cooling liquid
    - Wear according to the size of grinding granules
    - Forms of wear identified on processes with different wheels
    - Determined by the stone structure
    - Determined by the relative position of the grinding wheel in relation to the piece
  - **Cutting mediums**
    - No cooling liquid
    - Liquid and ultrasound cooling
  - **Heat**
    - Quantity of heat according to the wheel type
    - Influence of heat on wear
    - Tehniques of decreasing temperature in the contact area
    - Methods of measuring temperature in the contact area
    - Planning processing according to the contact temperature
    - Research regarding processing at high temperatures to modify the surface structure of the material to be processed
    - Quantity of heat according to the processing parameters and the wheel features
  - **Vibrations**
    - Determining vibrations
    - Beneficial and non beneficial influence on the process
  - ....
- **EQUIPMENT**
  - **Structure**
    - Material of grinding granules
    - Material of the binder
    - Porous materials
    - Transition metal carbides
    - Distribution of grinding granules
    - Determining the number of active granules
    - Shape of granules
    - Geometry of granules
    - Size of granules
    - Binder role in the process
  - **Shape**
    - Profile of the grinding wheel for processing complex profiles
    - Comparison between standard wheels and granule wheels
    - Abrasive ring type grinding wheels for processing nonmetallic spheres
    - Grinding stones with a special structure for processing surfaces with Cu and Ni metal covers
    - Grinding wheel with elastic elements
  - **Modelling**
    - Modelling the topography of the grinding stone with regular square pyramid shaped granules
    - Modelling the stone with granules of different sizes
    - Mathematical modelling of the total wear in relation to the probability of each type of wear
    - Modelling the process for synchronising the quantity of removed material with the blade wear
    - synchronising the quantity of removed material with the blade wear
  - **Defects**
    - Dislocation of granules
  - **Planning the grinding process**
    - Research in planning the grinding operation according to:
      - the minimal cost
      - optimal technological parameters
      - optimal cutting mode
    - Research in planning in the case of a rigid machine-tool-piece system
    - Research in planning the grinding process based on the determination of the kinematics of spherical pieces made from nonmetallic brittle materials
    - Research in planning the grinding process considering the maximization of the efficiency of the grinding process
  - ....

Fig. 2.27. Synthesis of research regarding the grinding process

3. THE SCOPE AND OBJECTIVES OF THE THESIS

Starting from the observations made during the documentation research, it was possible to define the objectives that are going to be reached during the research developed in the present thesis:

1. The systematic presentation of the current state of research regarding the grinding processing, in general, and metal carbides, in particular, following:
   - the theoretical aspects of the grinding process with application in metal carbides
   - the results of other analyses performed in relation to the grinding of different materials, especially those with high levels of hardness
   - the features of grinding wheels required in different processing situations
   - the interdependency between the factors involved in performing the process
2. The characterization of the grinding process for DK460UF metal carbides used in manufacturing cutting tools for processing deep holes.
3. Presenting the drills for deep holes and the requirements that are imposed for deep hole drill specific surfaces.
4. The study of the manufacturing technology for monobloc drills made of DK460UF carbide for processing deep holes with a small diameter and their resharpening.
5. The issues found in the grinding process and its shaping. The modelling of the temperature in grinding the DK460UF carbide.
6. The creation of a model for the grinding process of DK460UF metal carbides.
7. The planning and conducting of experimental research concerning the cutting forces, temperature, the wear of the grinding wheel and the roughness when processing DK460UF metal carbide and the identification of optimal processing parameters in manufacturing monobloc drills for deep holes with a small diameter.
8. The creation of models based on the data obtained in advance through experimenting and their validation, based on which the establishment of optimal processing parameters would be possible.
9. The establishment of the optimal grinding process for DK460UF metal carbide, used in manufacturing drills for deep holes with small diameters.

4. MODELLING THE GRINDING PROCESS

This chapter presents the models for the grinding process found in the scientific literature that represented a point of departure in shaping the grinding of DK460UF carbide.

4.1. Overview - model and modelling

In this paragraph, it defines ”the model”, the model attributes, the modelling process and the modelling stages and activities.

4.2. Modelling the processes and products

Efficient modelling requires an analysis of the interdependence between functional requirements and the modelling parameters. Also, it is necessary to rank the factors that significantly influence the analyzed process.

In the case of the grinding process, the ranking of factors was done using the ”Triple cross” method (French version), presented in paragraph 4.6.1.

4.3. Modelling and simulating the grinding process

The model of the grinding process is a simplified representation of the real process, which allows a much more faster evaluation of modifications of the real system.

Experts in the field of simulations recommend the successive increase of the model's complexity. Validation of the grinding process implies its simulation under known conditions, followed by the comparison of results with those of the real process.

4.3.1. The model of interdependence between the elements of the grinding process

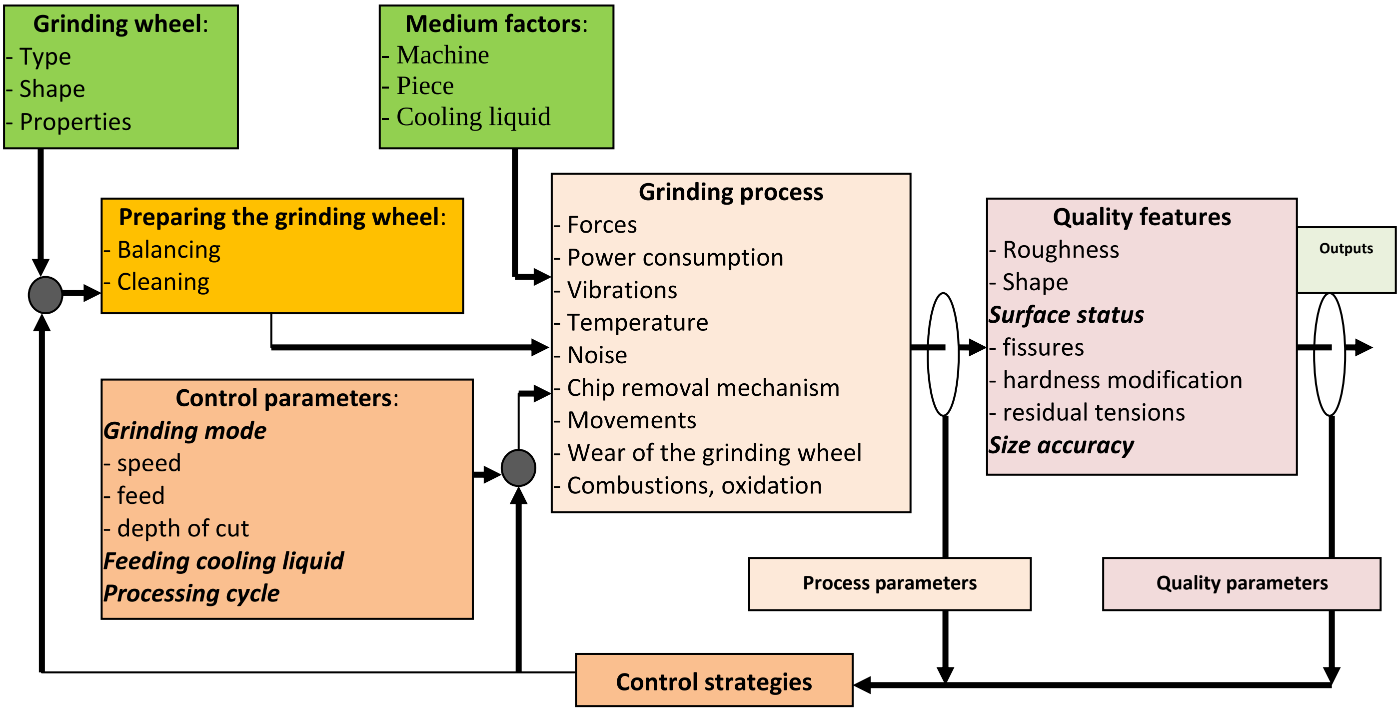


Fig. 4.5. The grinding process and the interdependency between the elements of the process [226]

As seen in figure 4.5., the grinding process is a function that depends on many variables, which determine the measurable output values, such as: the cutting force, the power consumption, the temperature in the contact area, the state of the processed surface, roughness, shape, size precision, the cost and productivity of the process. The variables that are part of the process are related to the cutting wheel, the machine tool, the cutting mode, etc.

4.4. Models of the grinding process

4.4.1. Modelling the machining process

After 1990, modelling and simulation witnessed an outstanding development, in line with the development of information systems and advanced technologies.

By running a comparative study between the research in the field of grinding to determine the interdependence of process parameters and the modelling and simulation of the grinding process, we can notice a significant increase of elaborate papers on the subject of modelling and simulation (fig. 4.6.).

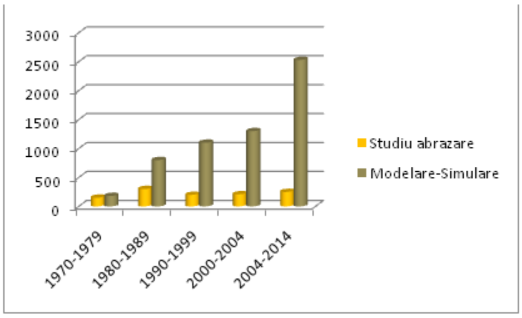


Fig. 4.6. Research evolution in grinding modelling and smulation [21]

4.4.2. Grinding process models

The grinding process is the sum of interactions between the abrasive granule and the surface to be processed and the models must describe the complexity of relations between the topography of the grinding wheel, the process kinematics and the features of the workpiece to be processed.

4.4.3. Empirical models

This paragraph describes the features of empirical models. Empirical models are mainly based on values measured during processing. The most relevant models are those that integrate knowledge based expert systems.

4.4.4. Analytical models

Analytical models are used to avoid «the black box» of empirical models.

Statistical methods take grinding into consideration as a cutting process in which all abrasive granules on the surface of the wheel that come in contact with the surface to be processed operate with the same depth of cut.

4.4.5. FEA – Finite Element Analysis

If kinematic modelling can be used as the basis for calculating the specific forces and energy, the modelling of physical elements of the process is a domain of finite element analysis –FEA.

To transfer the grinding process in a virtual medium, it is necessary to reduce the system variables. In this ideal model, all relevant parameters are integrated. The input parameters for a typical FEA simulation are: the geometry of the surface to be processed, the properties of the material to be processed, the cutting forces, the processing parameters, the coefficient of heat transfer between the cutting medium and the surface to be processed, etc.

4.4.6. Aplications of the process simulation

The FEA method allows a better understanding of the process and generates a complex analysis of experimental results.

For plane grinding, several models were created to simulate the distribution of heat during processing, under different conditions of applying the cooling liquid (fig. 4.15).

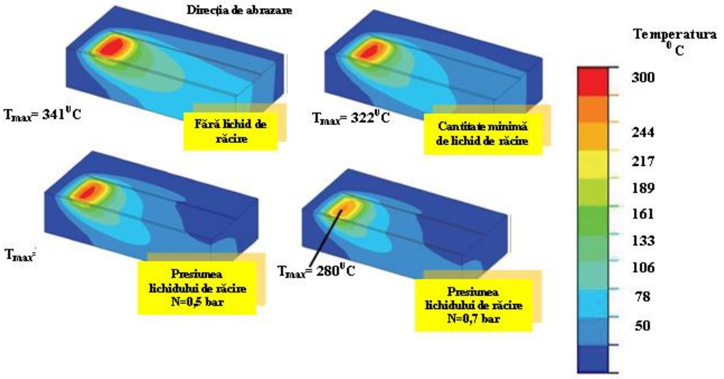


Fig. 4.15. Distribution of temperatures for different situations of applying the cooling liquid [70]

4.4.7. Modelling using statistical methods (Regression Analysis)

Regression analysis is the generic term of a statistical method that aims to find functional relations between dependent variables and one or two independent variables.

The models found in the scientific literature, independent of time, have targeted the modelling of the normal component of cutting forces. The coefficients and indexes are summarized in table 4.1. To apply these models it is necessary to examine closely the formulas of mathematical modelling.

Tabelul 4.1. Comparison between the coefficients of models created for normal component of the cutting force [21]

$F'_n = c_{wp} \cdot c_{gw} \cdot \left(\frac{1}{q}\right)^{e1} \cdot a_e^{e2} \cdot d_{eq}^{e3}$									
Grinding wheel		Input parameters			The coefficients of the model				
f_d	a_d	q	a_e	d_{eq}	$c_{wp} \cdot c_{gw}$	e1	e2	e3	
[mm]	[µm]	-	[µm]	[mm]	-	-	-	-	
EK80L7VX CK45 0,2	 3*20	60	50 - 250	32,7	19,74	0,74	0,87	0,13	1
EK60L7VX 100Cr6 0,2	 3*50	60-220	15-105	10-100	10,34	0,56	0,78	0,22	2
B126V180 100Cr6 -	 -	20-90	6-100	82,3	9,53	0,56	0,78	0,22	3
1. Konig / Werner 2. Peters / Decneut 3. Salje / Bock									

4.4.8. Modelling using artificial networks (ANN)

These models have a series of distinguishable properties that recommend them for modelling complex, unstable processes that depend on several input variables.

4.4.9. Knowledge based and expert system models

Knowledge Based System (KBS) refers to a knowledge based system that may offer solutions for a function that can be normally soled by human intelligence. Expert System refers to a type of specialized system based on knowledge that offers consultancy and is used for purposes of high specialization. [21]

4.5. Conclusions regarding the modelling of the grinding process

- The models developed using different modelling techniques are limited to the field of the various parameters that define the grinding process.
- The kinematic models come relatively close to the real grinding process.
- The finite element analysis creates the physical simulation of the entire process. The experiments and the materials required to verify the simulations are limited by the current measuring techniques.
- Regression analysis is another modelling technique, with the purpose of establishing certain relationships between the input and output parameters. The experiments and calculation of regression coefficients remain the main factors in choosing such models.

4.6. Modelling the grinding process for DK460UF carbide

4.6.1. Presentation of the DK460UF carbide

The DK460UF carbide is a wolfram (WC) carbide, manufactured through a process called powder metallurgy. Wolfram carbide powder is found at a rate of 91% , the rest of 9% representing the metal binder, cobalt.

The DK460UF material has grains that are the size of 0.5 and 0.6 μm.

4.6.2. Issues of grinding the DK 460 UF carbide

This metal carbide, with 91% WC and 9% Co, has specific properties, which influence the grinding processing. Thus, the small sizes of wolfram carbide grains cause good mechanical resistance, a high level of hardness, good thermal stability and great resistance to wear. These properties are perfect for the manufacturing of drills for deep holes of small diameters.

4.6.3. Ranking the issues of the grinding process using the "Triple Cross" method

The general model of grinding metal carbides, which was elaborated by researching models in the scientific literature, represented the starting point for determining the importance of the factors influencing the grinding process of the DK460UF metal carbide. (fig. 4.33)

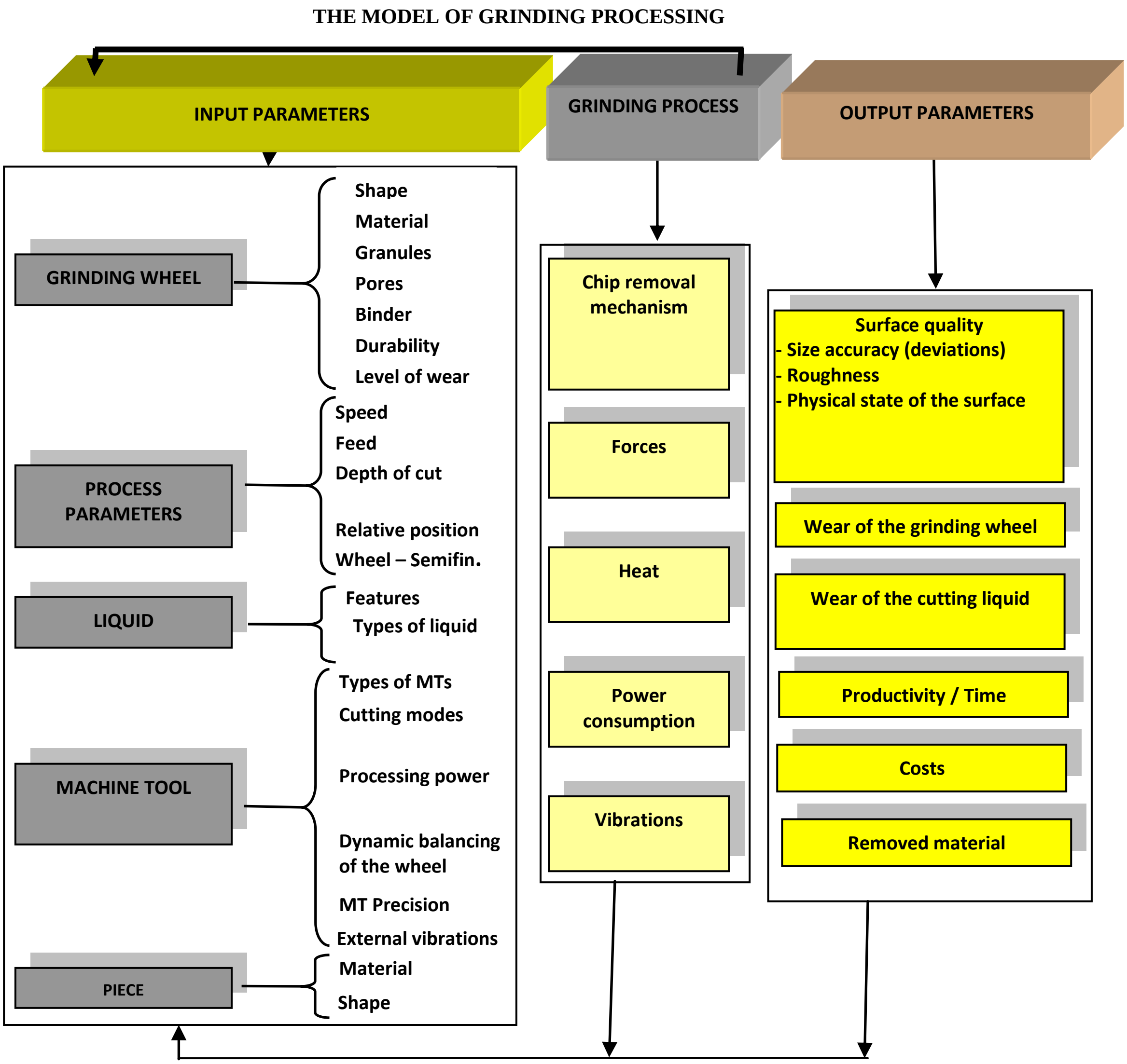


Fig. 4.33. Model of grinding processing

To plan an optimal grinding process for the general processing of metal carbides and the particular processing of deep drills, I propose the evaluation criteria of the grinding process presented in figure 4.34.

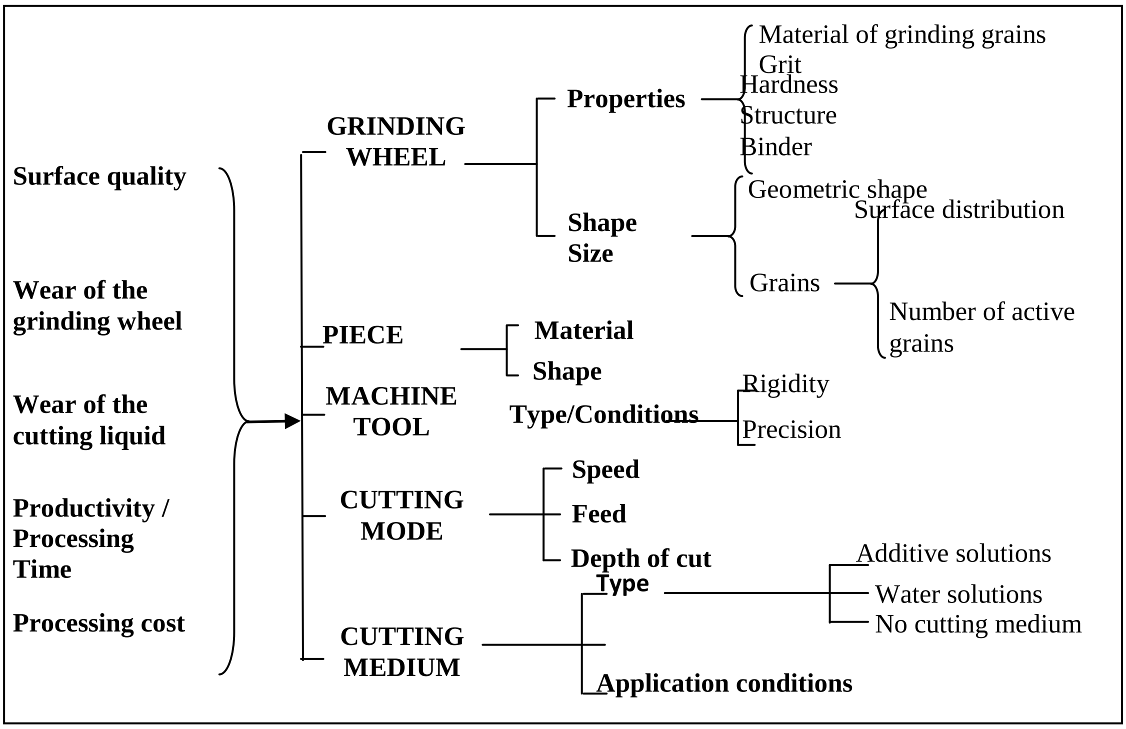


Fig. 4.34. Synthesis of evaluation criteria for the grinding process

Following the evaluation criteria suggested in the figure above, I have identified the need for a correct grinding of the deep hole drilss made from metal carbide.

By identifying the input parameters that influence each output of the grinding process, I have ranked them using the “triple cross” method.

By analogy, the relative importance of each element that takes part in the process was determined for each output.

🟨 **FP Number:**	**2**
🟦 **FC Number:**	**3**
🟧 **TOTAL**	**5**

/ : equal importance
1 :slightly superior
2 :superios on average
3 : clearly superior

FP1	FP2	FC1	FC2	FC3
FP1	FP2 3	FP1 2	FC2 3	FP1 2
	FP2	FC1 1	FP2 /	FP2 3
		FC1	FC2 3	FC3 2
			FC2	FC2 2
				FC3

Functions	**Points**	**%**
FP1	**4**	**19.0%**
FP2	**6**	**28.6%**
FC1	**1**	**4.8%**
FC2	**8**	**38.1%**
FC3	**2**	**9.5%**
	TOTAL : 21	**100 %**

For size accuracy, the important requirements are the initial state of the grinding wheel 38%, the accuracy of the machine tool 28%, the rigidity of the machine tool 19%. (figure 4.35)

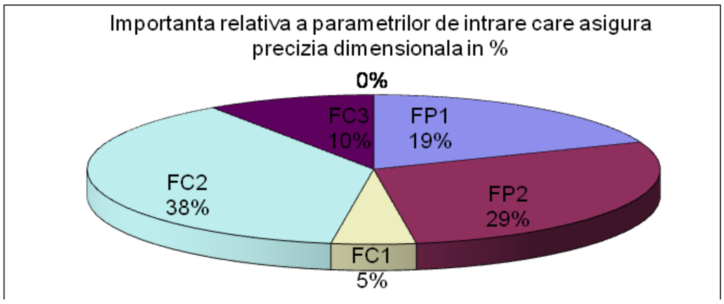


Fig. 4.35. Ranking the input parameters that influence size accuracy

The important requirements of roughness are the properties of the grinding wheel 41,7%, the depth of cut 20,8%, the feed and the speed of grinding 16,7%.

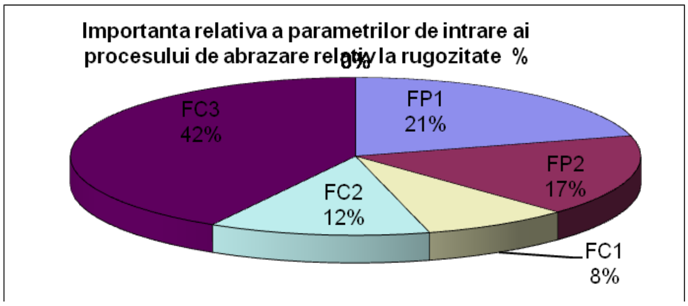


Fig. 4.36 Ranking the input parameters that influence surface roughness

It may be observed that the chemical – physical state of the surface is influenced by the wear of the grinding wheel 29,1%, the depth of cut 21,8%, the cutting speed 21,2% and the size of the contact area between the grinding wheel and the processed surface 12,7%.

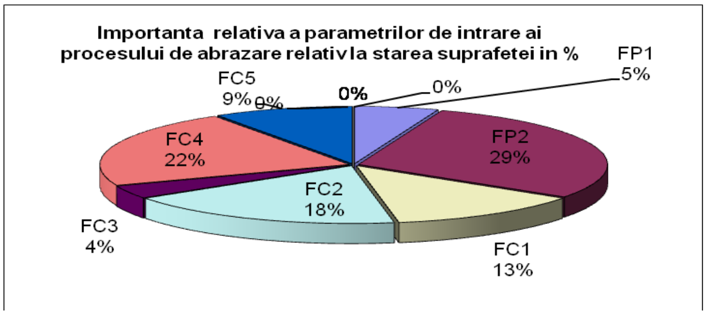


Fig. 4.37. Ranking the input parameters that influence the surface state

Starting from the general requirements of an efficient grinding process, but also from the specific conditions of grinding metal carbides and in particular from the processing of deep cutting drills of a small diameter, all the requirements will be stated, ranked and finally, the most significant for ensuring an optimal machining process will be selected, after which an optimal model for the grinding process of these tools will be created. (fig. 4.40)

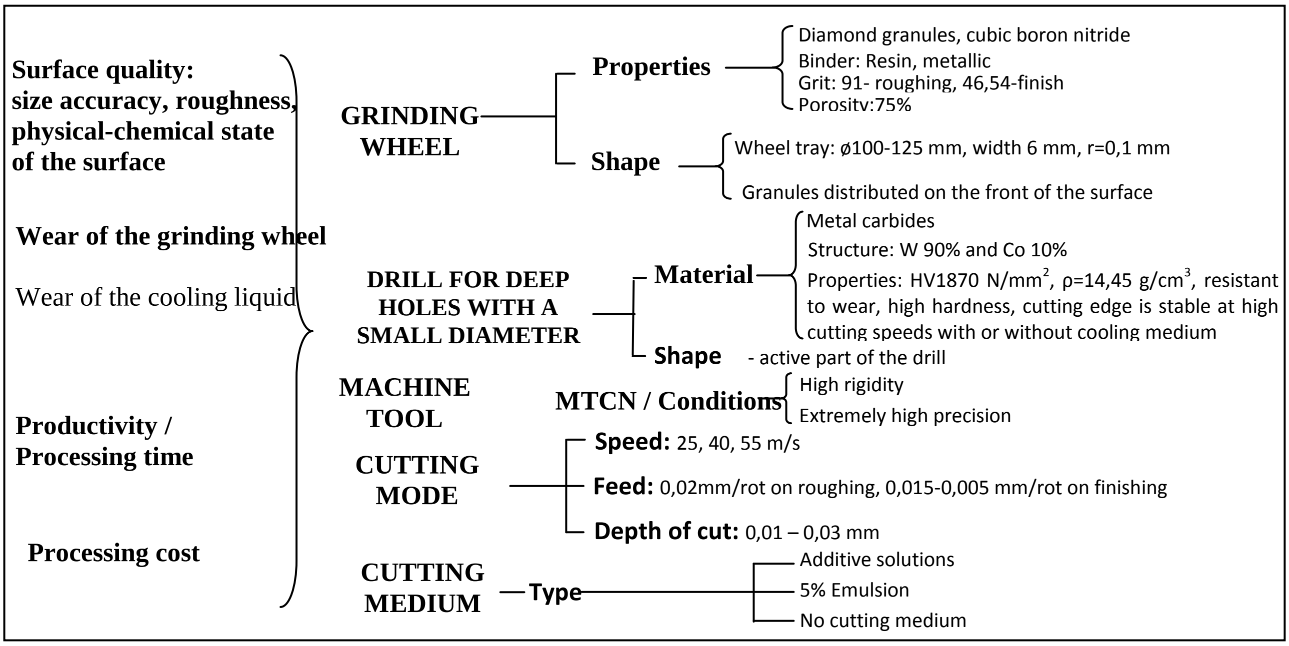


Fig. 4.40. Synthesis of grinding conditions for metal carbide drills for processing deep holes with a small diameter

Observations:

- The grinding wheel must be made of diamond or cubic boron nitride grinding granules, distributed in a mineral binder (resin), the wheel being of high porosity;
- The roughness of grounded surfaces must be low, must have values between 0,225 µm and 0,4 µm. It depends on the grit of the grinding material, the structure of the wheel and the cutting mode.
- The cutting mode significantly influences the grinding process; processing must take place at a high cutting speed, 55 m/s, a low depth of cut, 0,015 mm and a small feed, 0,005 mm/rot.
- The normal and tangent components of the cutting force depend on the cutting speed and the depth of cut. They must have low values and represent an indicator of wear for the grinding wheel.
- The adequate use of the cooling liquid is important for reducing the generated heat and for avoiding thermal defects of the tip and blade of the drill; a water and oil emusion of 5% is used - PETROFERSUPERFIN, at a pressure of 1 MPa, recommended for the quality imposed for the surface of drills for deep holes of small diameters.
- To process small size surfaces, such as the surface of drills for deep holes of small diameters, the distribution of granules on the front surface of the grinding wheel is important
- The heat generated in the cutting process may lead to defects in the processed surface and the damaging of the components of the processing system.

4.7. Finite element modelling of the temperature flow

4.7.1. Calculating the temperature flow and the maximum temperature

Jaeger’s model was used to calculate the temperature, in which the grinding wheel is represented as a heat source, evenly distributed on the length of the contact area between the piece and the wheel, moving along the piece at a speed equal to the speed of the piece.

Processed material:

DK460UF carbide: WC – 91% and Co - 9%

Table 4.3. Properties of DK460UF metal carbide

Maximum temperature of use (**^{0}C**)	Thermal conductivity **W/(m K)**	Specific heat **J/(K kg)**	HV Hardness **Kg / mm^2**	Density **g / cm^3**	Young's Module **GPa**	Poisson Coefficient
1000	73.0 - 100.0	200 - 480	1730 - 2400	12 - 15.8	600 - 715	0.24

1. Calculating the contact length

The following formula is used: $l_c = \sqrt{a_p \cdot d_s}$ (4.1.)

where a_p is the depth of cut, d_s is the diameter of the grinding wheel.
Data used: d_s = 300 mm, 180 mm respectively, a_p = 0,015 mm, 0.025 mm respectively

Table 4.4. Contact length for different depths of cuts and different wheels

No.	Wheel diameter d_s [mm]	Depth of cut a_p [mm]	Contact length l_c [mm]
1	300	0,015	2,12
2	300	0,025	2,74
3	180	0,015	1,64
4.	180	0,025	2,12

2. Calculating the temperature flow

The temperature flow is calculated using the formula:

$$Q = \varepsilon \cdot \frac{F_t^I \cdot v_s}{l_c} \qquad (4.6.)$$

where ε is the amount of heat in the piece, in percentages, F_t^I is the tangent force per piece width unit, v_s is the peripheral speed of the grinding wheel, l_c is the contact length.

$$\varepsilon = \frac{0{,}55 \cdot u_{ch} + u_{pl} + u_{sl}}{u} = \frac{u - 0{,}45 \cdot u_{ch}}{u} \Rightarrow \varepsilon = 1 - 0{,}45\,\frac{u_{ch}}{u} \qquad (4.8)$$

u_{ch} is a constant equal to 26,7 J/mm^3.

$$u = \frac{F_t' \cdot v_s}{a \cdot v_w} \qquad (4.9)$$

where v_w is the speed of the piece, F_t' - specific tangent force.

Table 4.5. Specific tangent force for the two grinding wheels

No.	Wheel diameter, d_s [mm]	Depth of cut, a_p [mm]	Tangent force per piece width unit F'_t [N/mm]
1	300	0,015	4,58
2	300	0,025	5,05
3.	180	0,015	2,75
4.	180	0,025	3,25

Table 4.6. Temperature flow values according to the speed and depth of cutting

No.	Wheel diameter d_s [mm]	Depth of cut a_p [mm]	Experimentally	Results from calculations			
			F'$_t$ [N/mm]	u [J/mm^3]	ε [%]	l_c [mm]	Q [W/mm^2]
1.	180	0,015	2,75	34,375	0,819	1,64	34,33
2.	180	0,025	3,25	24,375	0,745	2,12	28,55
3.	300	0,015	4,58	91,6	0,932	2,12	80,53
4.	300	0,025	5,05	60,6	0,897	2,74	66,13

2. Calculating maximum temperature:

$$\theta_m = \frac{\beta \cdot \alpha_w^{1/2} \cdot \varepsilon \cdot P}{k_w \cdot b \cdot d_s^{1/4} \cdot v_w^{1/2} \cdot a^{1/4}} \tag{4.10}$$

where, θ_m is the maximum temperature, β is the constant depending on the shape of the heat source (β = 1,13 for rectangles, β = 1,06 for triangles), α_w is the thermal diffusion within the piece, ε is the percentage of heat in the piece, P is the grinding power, k_w is the thermal conductivity of the piece material, b is the contact width, d_s is the wheel diameter, v_w is the velocity of the piece, a_p is the depth of cut.

1. $a_p = 0{,}025$ mm, $\Theta = 476^0$C
2. $a_p = 0{,}015$ mm, $\Theta = 461{,}41^0$C

4.7.2. Finite element analysis of the temperature flow

To create the model for temperature in the contact area the ABAQUS 6.13.4 software is employed.

The metal carbide under study is a parallelepiped of 110x20x10 size.

The model is analyzed, taking into account the heat transfer in thermal equilibrium (stationary). The interaction is a surface – medium one. Medium conductivity (air) = 20. It is the same for each step. It is considered that the medium temperature is evenly distributed and is 23^0 C. The calculated thermal flow was applied, with variable values according to the values of the cutting mode.

Heat transfer models result according to the cutting speed and depth of cut.

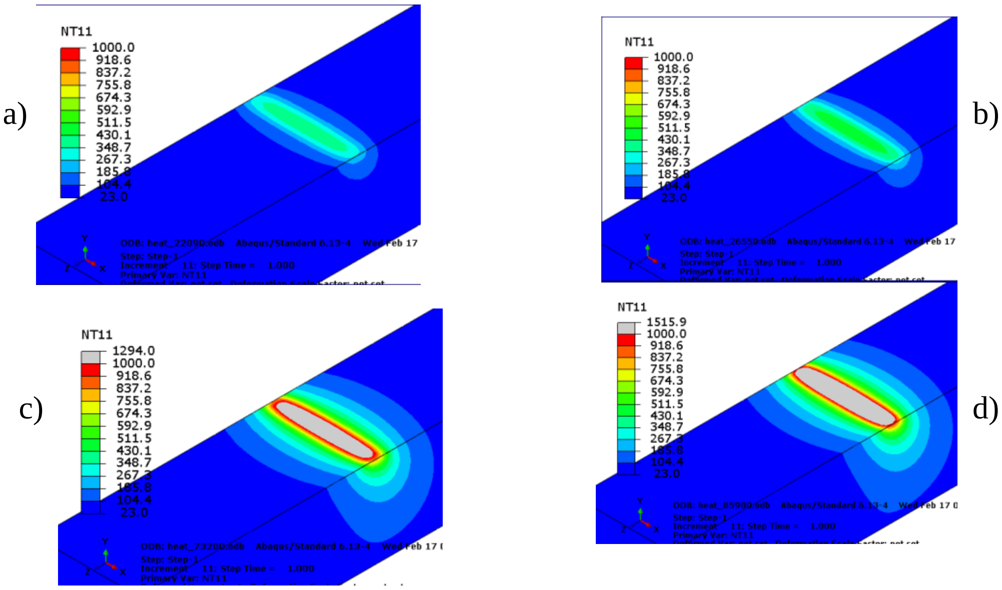


Fig. 4.53. Variation of heat flow in the contact area *a) v = 25 m/s, a_p = 0.015 mm b) v = 25 m/s, a_p = 0.025 mm c) v = 40 m/s, a_p = 0.015 mm d) v = 40 m/s, a_p = 0.025 mm*

The heat flow depends on the cutting mode parameters. It may be observed that the temperature rises with the increase of the cutting speed, correlated with the increase of the depth of cut, result that was also obtained through experiments.

5. MONOBLOC CUTTING TOOLS FOR PROCESSING DEEP HOLES OF SMALL DIAMETER

In this chapter, the manufacturing technology for metal carbide drills for deep holes of small diameters is presented.

5.1. Overview

The quality of deep holes refers to size, circularity, roughness, rectilinearity, perpendicularity, hardness. Research performed in the field of deep holes has proven that this quality features may be simultaneously met in the case of processing with deep hole drills. This type of drill also ensures the finishing of the hole surface, besides the actual processing, not requiring further finishing, in general, for diameters smaller than 20 mm. [3]

5.2. Deep hole drills

5.2.1. Gundrills

5.3. Materials for manufacturing deep hole drills

DK460UF wolfram carbide, used in our research, contains 91% WC and 9% Co. It is used in the production of machine tools. Machine tools that operate under special conditions, related to the evacuation of chips, to the cooling of the active part, to the reduction of efforts, such as drills that have a large cutting length and a relatively low rigidity require strict specifications regarding processing, machine tools and related equipments. A large number of mentioned disadvantages may be removed by manufacturing these tools out of DK460UF carbide, which offers high resistance to wear, as well as thermal and mechanical resistance. The roughness of the active surfaces plays an important part in the durability of these tools. These carbides that are widely used in the production of cutting tools needed for processing materials that have a high level of hardness with the purpose of obtaining a high-quality surface increase productivity and reduce the processing time. The quality of the surface requires a low level of roughness and a strict form precision.

5.4. Semi-products used in manufacturing drills for deep holes of a small diameter

5.4.1. Types of semi-products from metal carbides

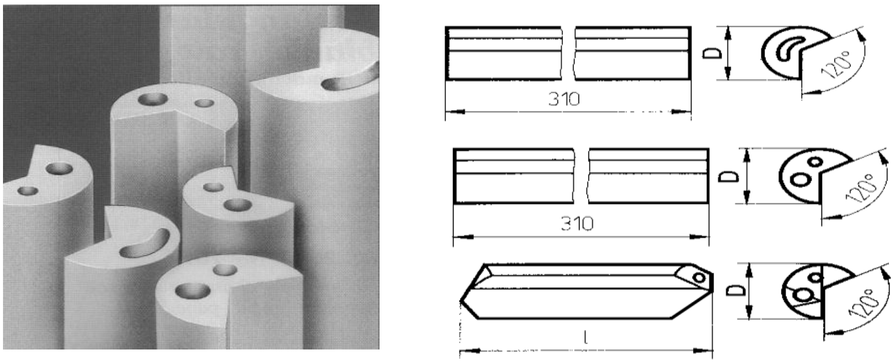


Fig. 5.4. Semi-products for drill heads for deep holes with straight openings and different shapes for the cooling - lubrication liquid

5.5. Numerically controlled machine tools for manufacturing and sharpening deep hole drills

5.5.3. Designing the manufacturing technology for cutting tools for processing holes

5.6. Grinding wheels

5.7. Grinding processing of carbides for manufacturing drills for deep holes of a small diameter

5.7.1. Factors that determine the structure of the grinding processing of carbides for manufacturing drills for deep holes of a small diameter

5.7.2. Factors that influence the surface quality for drills for deep holes of a small diameter

5.7.3. The processing technology of a drill for deep holes of small diameter

„TOOLdefine” software module is especially created to build a cutting tool with a new geometry that does not exist in the database of the application.

Stages of constructing a cutting tool using the application:

1. Choosing the type of cutting tool and its basic geometry. It will be performed in a selection window in which we will choose:

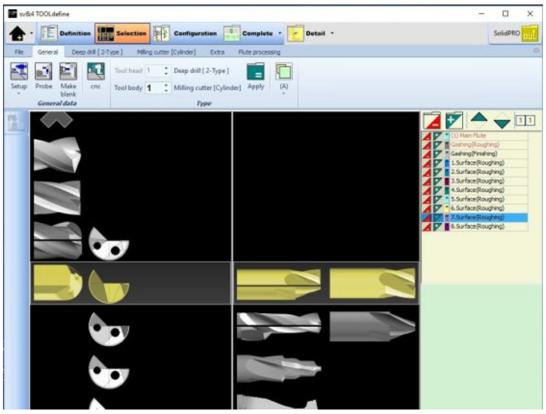
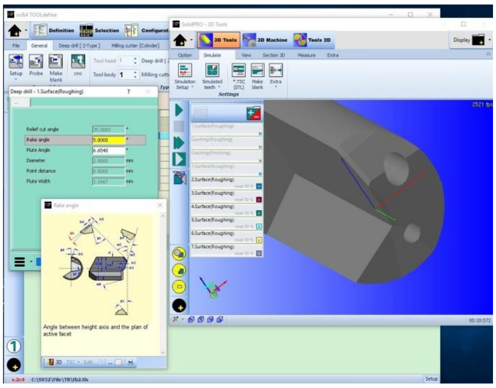


Fig. 5.20. Choosing the basic geometry of a deep hole drill

2. **Entering the data that defines the drill geometry**


Deep drill - 1.Surface(Roughing)

Relief cut angle 35.0000 °

Rake angle 5.0000 °

Flute Angle 6.6540 °

Diameter 2.0000 mm

Point distance 0.5000 mm

Flute Width 1.1667 mm

Angle between height axis and the plan of active facet

Fig. 5.21. Entering the data that defines the drill geometry

3. Choosing the grinding wheel

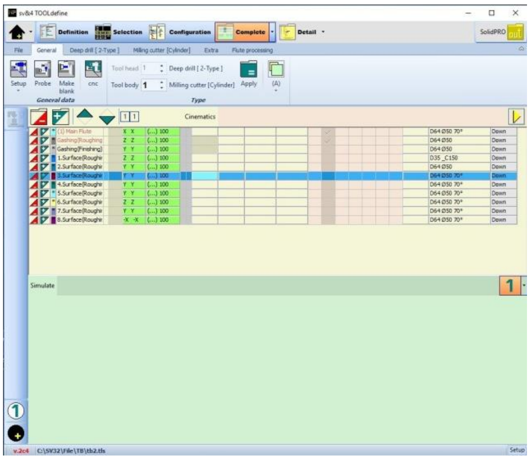


Fig. 5.22. Choosing the grinding wheel

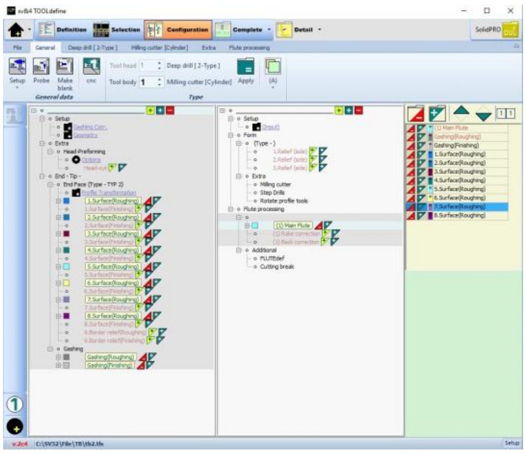


Fig. 5.23. Production technology and initializing additional data

4. Production technology

Figure 5.23. represents the window that contains the entire production technology of the cutting tool.

Visualizing the machining process.

The „*SolidPRO*” software module offers the possibility to visualize the entire technological process, step by step.

Figure 5.24. represents the simulation of the machining process on a numerically controlled machine tool.

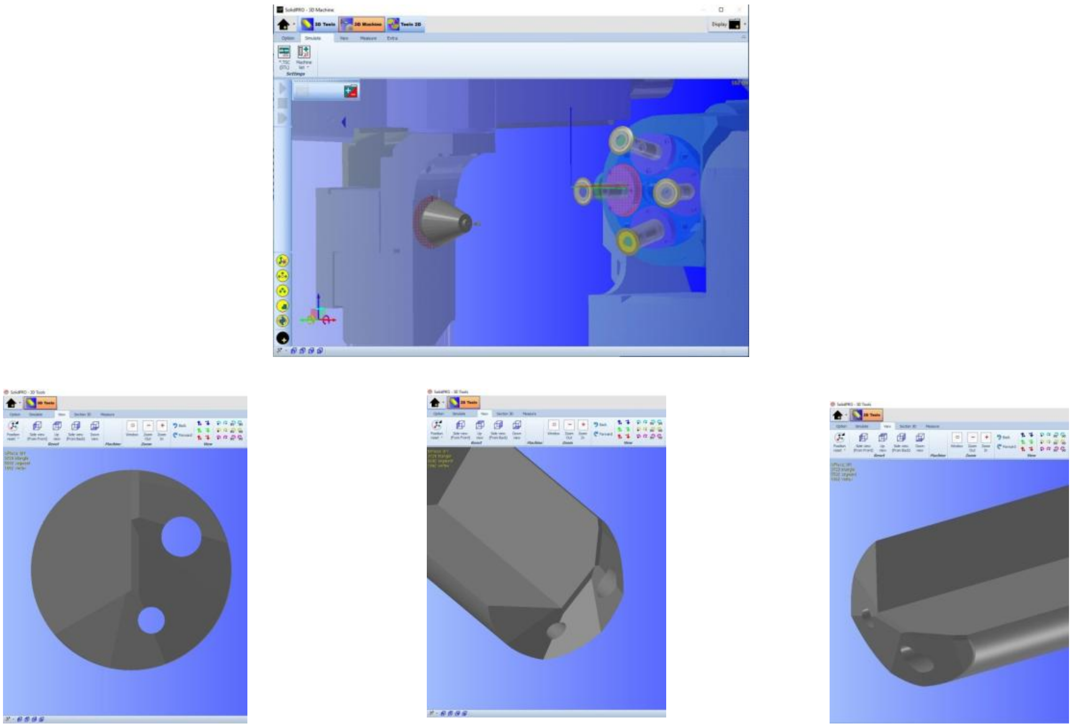
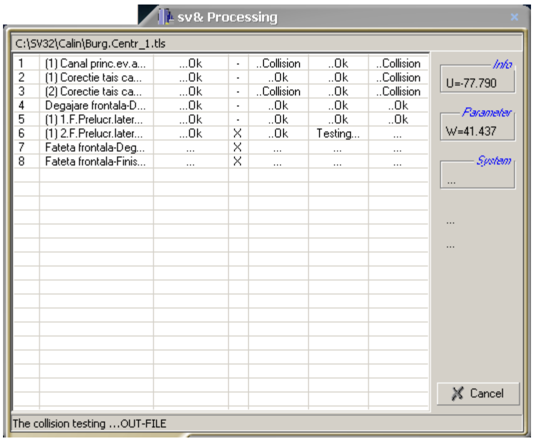


Fig. 5.24. Simulating the machining process on a NCMT

Simulation using the „*3D – Collision*” tridimensional simulator.

An important issue is the collision between the moving subassemblies of the machine tool, the occurrence of which would lead to significant damages and material losses.

In this way it is verified, step by step, if these trajectories intersect and the collision points, the exact moment of the collision and the duration of the collision are determined.



C:\SV32\Calin\Burg.Centr_1.tls

1	(1) Canal princ.ev.a...	...Ok	-	..Collision	..Ok	..Collision
2	(1) Corectie tais ca...	...Ok	-	..Ok	..Ok	..Collision
3	(2) Corectie tais ca...	...Ok	-	..Collision	..Ok	..Collision
4	Degajare frontala-D...	...Ok	-	..Ok	..Ok	..Ok
5	(1) 1.F.Prelucr.later...	...Ok	-	..Ok	..Ok	..Ok
6	(1) 2.F.Prelucr.later...	...Ok	X	..Ok	Testing...	...
7	Fateta frontala-Deg...	...	X	...	...	...
8	Fateta frontala-Finis...	...	X	...	...	...

Info: U=-77.790

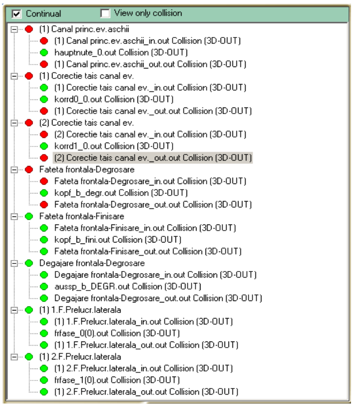
Parameter: W=41.437

System: ...

The collision testing ...OUT-FILE

Fig. 5.25. **Window for the calculation of operational collisions**

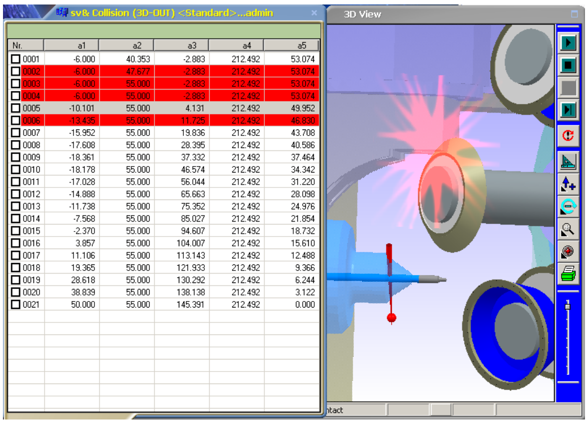
By selecting that operation stage, the “collision film” can then be watched.



☑ Continual ☐ View only collision

- ● (1) Canal princ.ev.aschii
  - ● (1) Canal princ.ev.aschii_in.out Collision (3D-OUT)
  - ● hauptnute_0.out Collision (3D-OUT)
  - ● (1) Canal princ.ev.aschii_out.out Collision (3D-OUT)
- ● (1) Corectie tais canal ev.
  - ● (1) Corectie tais canal ev._in.out Collision (3D-OUT)
  - ● korrd0_0.out Collision (3D-OUT)
  - ● (1) Corectie tais canal ev._out.out Collision (3D-OUT)
- ● (2) Corectie tais canal ev.
  - ● (2) Corectie tais canal ev._in.out Collision (3D-OUT)
  - ● korrd1_0.out Collision (3D-OUT)
  - ● (2) Corectie tais canal ev._out.out Collision (3D-OUT)
- ● Fateta frontala-Degrosare
  - ● Fateta frontala-Degrosare_in.out Collision (3D-OUT)
  - ● kopf_b_degr.out Collision (3D-OUT)
  - ● Fateta frontala-Degrosare_out.out Collision (3D-OUT)
- ● Fateta frontala-Finisare
  - ● Fateta frontala-Finisare_in.out Collision (3D-OUT)
  - ● kopf_b_fini.out Collision (3D-OUT)
  - ● Fateta frontala-Finisare_out.out Collision (3D-OUT)
- ● Degajare frontala-Degrosare
  - ● Degajare frontala-Degrosare_in.out Collision (3D-OUT)
  - ● aussp_b_DEGR.out Collision (3D-OUT)
  - ● Degajare frontala-Degrosare_out.out Collision (3D-OUT)
- ● (1) 1.F.Prelucr.laterala
  - ● (1) 1.F.Prelucr.laterala_in.out Collision (3D-OUT)
  - ● frfase_0(0).out Collision (3D-OUT)
  - ● (1) 1.F.Prelucr.laterala_out.out Collision (3D-OUT)
- ● (1) 2.F.Prelucr.laterala
  - ● (1) 2.F.Prelucr.laterala_in.out Collision (3D-OUT)
  - ● frfase_1(0).out Collision (3D-OUT)
  - ● (1) 2.F.Prelucr.laterala_out.out Collision (3D-OUT)

Fig. 5.26. **Collision film in the technological machining process**



Nr.	a1	a2	a3	a4	a5
☐ 0001	-6.000	40.353	-2.883	212.492	53.074
☐ 0002	-6.000	47.677	-2.883	212.492	53.074
☐ 0003	-6.000	55.000	-2.883	212.492	53.074
☐ 0004	-6.000	55.000	-2.883	212.492	53.074
☐ 0005	-10.101	55.000	4.131	212.492	49.952
☐ 0006	-13.435	55.000	11.725	212.492	46.830
☐ 0007	-15.952	55.000	19.836	212.492	43.708
☐ 0008	-17.608	55.000	28.395	212.492	40.586
☐ 0009	-18.361	55.000	37.332	212.492	37.464
☐ 0010	-18.178	55.000	46.574	212.492	34.342
☐ 0011	-17.028	55.000	56.044	212.492	31.220
☐ 0012	-14.888	55.000	65.663	212.492	28.098
☐ 0013	-11.738	55.000	75.352	212.492	24.976
☐ 0014	-7.568	55.000	85.027	212.492	21.854
☐ 0015	-2.370	55.000	94.607	212.492	18.732
☐ 0016	3.857	55.000	104.007	212.492	15.610
☐ 0017	11.106	55.000	113.143	212.492	12.488
☐ 0018	19.365	55.000	121.933	212.492	9.366
☐ 0019	28.618	55.000	130.292	212.492	6.244
☐ 0020	38.839	55.000	138.138	212.492	3.122
☐ 0021	50.000	55.000	145.391	212.492	0.000

Fig. 5.27. **Windows for displaying the operation steps and for visualizing the collision step by step**

5.8. Conclusions

1. The study of deep hole drills has emphasized the features required to ensure an accurate processing of holes and a long lifespan of the cutting tool.
2. To increase the productivity of deep hole drills, semi-products are used, which have holes for the cooling liquid, thus decreasing the number of processing operations. To obtain cutting tools of increased durability, metal carbides are employed.
3. The elaboration of the processing technology must take into account aspects related to material, the geometry of the drill and the technological equipment employed.
4. The development of software applications has reduced the planning duration of the processing technology.
5. Using ”TOOLdefine”, we have planned the execution technology for a deep hole drill and using „***SolidPRO***”, we have visualized the entire technological process. Simulators help to visualize planning errors but also information regarding the existence of situations in which collisions between the components involved in the grinding process may occur.

6. EXPERIMENTAL RESEARCH ON THE GRINDING PROCESS OF DK460UF METAL CARBIDES

6.1. Overview

6.2. Planning the experiment

6.2.1. The stages of experiment design

6.2.2. Defining the variables of the experiment in the field of study [39]

6.2.3. Selecting the variation levels for independent variables

6.2.4. Executing the experiment plan

6.2.5. Classification of experiments

6.2.5.1. Experimental plans

6.2.5.2. Factorial experiments

6.2.6. The statistical analysis of experimental data

6.2.7. Determining the mathematical model for the experiment.

6.2.8. Decisions following the modelling through a factorial experiment

6.2.9. Presentation of Design-Expert V7.0 software.

6.3. Planning experimental research to monitor the grinding process of DK460UF metal carbides

To plan an optimal grinding process for processing metal carbides in general and deep hole drills in particular, the general model for the grinding process was the starting point, the main output parameters being the quality of the processed surface and the wear of the grinding wheel.

6.3.2. The model of conducted experimental research

Figure 6.5. presents the model of experimental research**.** Models for the cutting forces, temperature, wear and roughness of the processed surface will be created for different cutting modes, working with grinding wheels of different grits. The resulting models are used in determining the optimal parameters of the cutting mode when processing the active surfaces of drills for deep holes with a small diameter.

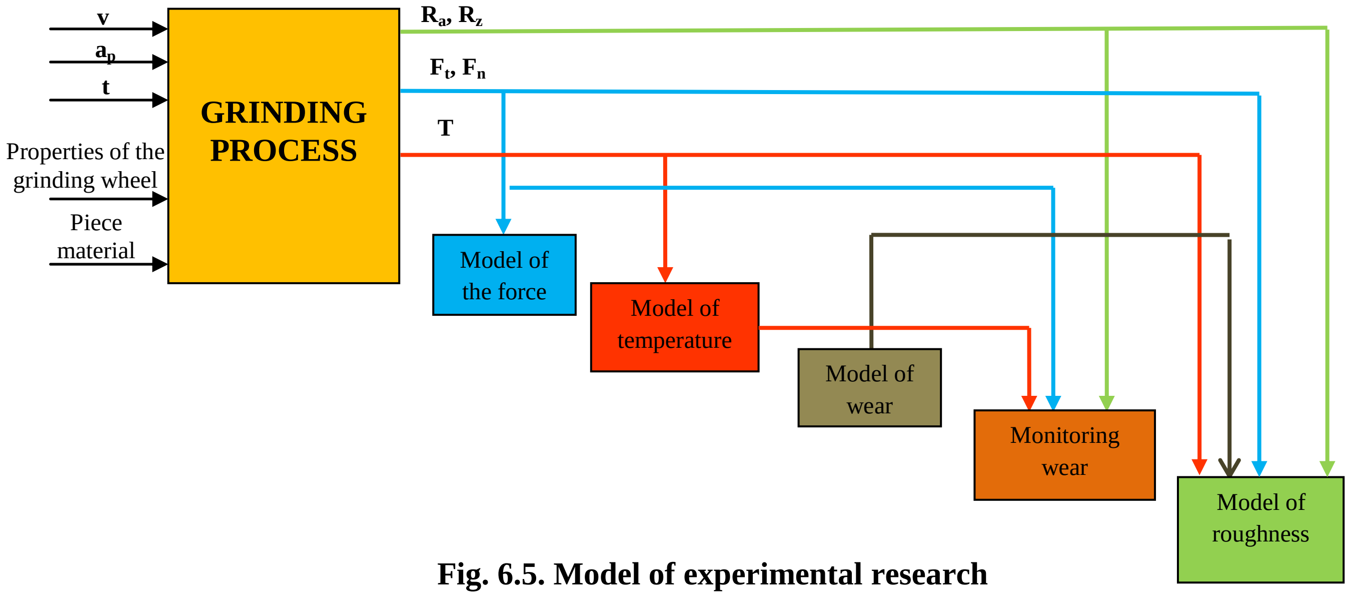


Fig. 6.5. Model of experimental research

6.3.3. Establishing the plan of experiments and the levels of variation of the factors

Within experimental research, several attempts were made in which the parameters of the cutting mode and the properties of the grinding wheel vary between the following limits:

- cutting speed, v = 40 ÷ 60 [m/s]
- feed, f = 0,005 ÷ 0,008 [mm / rot]
- depth of cut, a_p = 0,01 ÷ 0,03 [mm]
- grit of the grinding wheel, 46 µm, 54 µm respectively

Also, within experimental research, the status of the grinding wheel was taken into account, as well as the degree of wear. Attempts were made using new wheels, as well as used wheels, so that the variation of monitored elements in the process is determined based on the main factors that influence the processing of surfaces.

6.4. The study of forces in the process of grinding DK460UF metal carbide

6.4.1. Selecting the type of experiment

The grinding force will be studied according to the two components, the tangent and normal forces, which have a significant influence in the grinding process.

Following the analysis performed on the process, modelling using a complete type 2^3 factorial experiment was chosen. The factorial experiment was used in modelling each component.

6.4.2. Planning the experiment and taking measurements

Experiments were conducted on a plane grinding machine. A prismatic DK460UF metal carbide piece, with the following measurements: 20x50x100 mm, hardness 1620 HV, granule size 0.5 µm, was processed.

2 grinding wheels with diamond granules were used, having the following features:

Wheel 1: D54 – 250 mm diameter, 10 mm width, 54 µm grit.

Wheel 2: D54 –180 mm diameter, 10 mm width, 54 µm grit.

The Kiestler dynamometer was used for measurement. (fig. 6.10.)

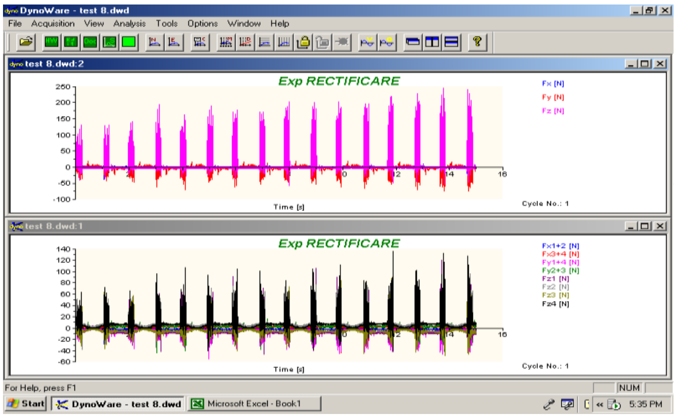
Fig. 6.10. Measurement forces with Kiestler 9255B dynamometer

Table 6.1. Variation levels of the influencing factors and the coordinates of the central point of the experiment for the F_t, F_n component

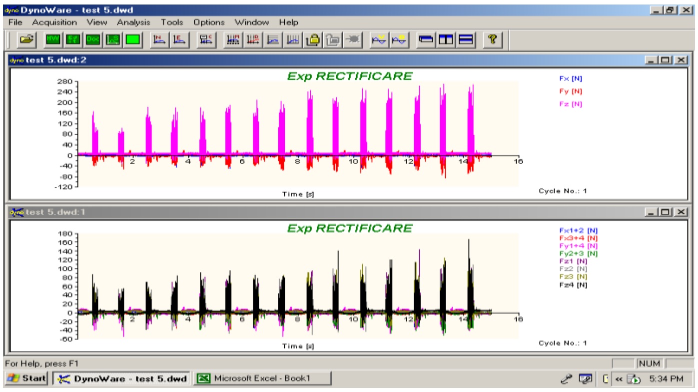
Parameter	Codified value	Physical value		
		$x_1 \Leftrightarrow v$ [m/s]	$x_2 \Leftrightarrow f$ [mm/troke]	$x_3 \Leftrightarrow a_p$ [mm]
Central point, x_{j0}	0	43	0.2	0.02
Variation interval, D_j	Δ_j	7	0.05	0.01
Superior level, x_{jsup}	+1	50	0.25	0.03
Inferior level, x_{jinf}	-1	36	0.15	0.01

Table 6.2. Measured values of the cutting forces when processing with new wheels

No.	Speed v [m/s]	Feed f [mm/troke]	Depth of cut a_p [mm]	F_t [N]	F_n [N]
1	50.000	0.250	0.01	45.860	98.480
2	36.000	0.150	0.01	29.260	76.860
3	36.000	0.250	0.03	50.530	107.410
4	36.000	0.150	0.03	48.070	95.230
5	50.000	0.150	0.01	19.210	65.050
6	50.000	0.250	0.03	37.670	77.540
7	36.000	0.250	0.01	41.420	91.480
8	50.000	0.150	0.03	27.350	79.670



a) f=0,15 mm/stroke, a_p=0,01 mm



b) f=0,15 mm/stroke, a_p=0,03 mm

Fig. 6.11. Values of cutting force components in relation to $a_{p,}$ v=50 m/s

6.4.3. Construction of the program-matrix of the experiment

As stated, the variation of factors on two levels is enough, resulting in the maximum volume of the experiment, $N=2^k$.

6.4.4. Determining the mathematical model of the experiment and its analysis

$$F_t = -\,250.36+14.68\cdot v -732.80\cdot f+1720.55\cdot a_p-4.17\cdot v\cdot f-42.61\cdot v\cdot a_p+5472.40\cdot f\cdot a_p -0.15\cdot v^2+ +1902.84\cdot f^2 -25253.38\cdot a_p^2 \qquad (6.14)$$

$$F_n= -\,1011.32+59.92\cdot v-3229.46\cdot f+8192.85\cdot a_p-17.41\cdot v\cdot f-196.99\cdot v\cdot a_p+19706.19\cdot f\cdot a_p - -\,0.60\cdot v^2+8470.21\cdot f^2-101153\cdot a_p^2 \qquad (6.15)$$

The influence of each parameter and the adequacy of the model are determined by performing the ANOVA analysis on the obtained models of force (fig. 6.16).

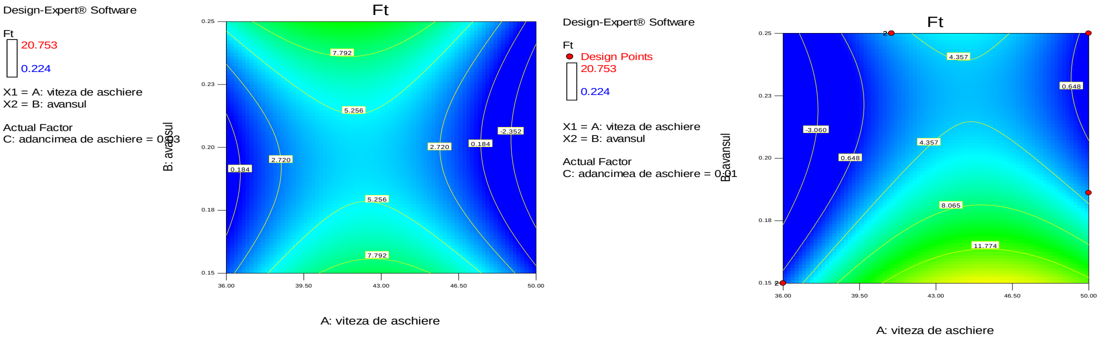


Fig. 6.16. Variation of F_t force in relation to the cutting mode parameters

The tangent component of the cutting force depends on the cutting mode parameters. It may be observed that it depends on the cutting speed, the depth of cut and the feed.

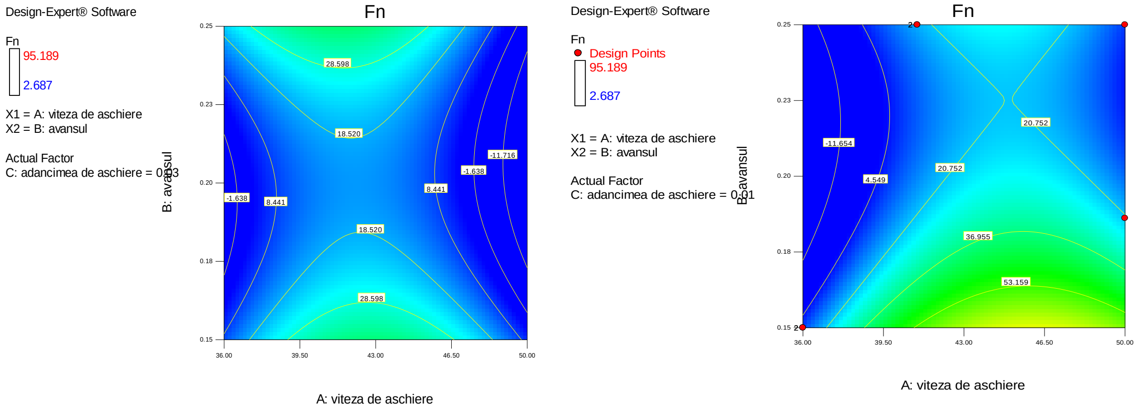


Fig. 6.19. Variation of F_n force in relation to the cutting mode parameters

The normal component of the grinding force is influenced by the cutting mode parameters and the variations are more significant than in the case of the tangent component.

6.4.5. Variation of forces in relation to the degree of wear of the grinding wheel

6.4.5.1. Defining the research objective

The experiment monitors the influence of the radial wear of the grinding wheel on the cutting force.

6.4.5.2. Selecting the objective function

The objective functions are the components of the grinding force, the tangent force and the normal force respectively.

6.4.5.3. Planning the experiments and acquiring data

The D54P150/A-C100 grinding wheel was used to process batches of 50 pieces made out of DK460UF metal carbide, until catastrophic wear set in. After each 50 piece batch, the radial wear of the wheel was measured and then the grinding force was measured. The cutting mode employed was: v = 55 m/s, f = 0.005 mm/rot, a_p = 0.01 mm.

The measurement of the radial wear was done using the Walter Helicheck Basic Optical CNC measuring machine (fig.6.32), and the forces were measured using the Kiestler dynamometer (fig. 6.10).

Tabel 6.4 includes the measured values of the cutting force components when processing using a grinding wheel at different stages of wear, according to the number of processed pieces.

Table 6.4.

No. pieces	Radius variation [µm]	$F_{t\ disc\ uzat}$ [N]	$F_{ndisc\ uzat}$ [N]
50	4.25	50.35	100.50
100	7.75	56.26	110.42
150	9.45	62.34	127.54
200	11.50	65.67	144.52
250	15.70	72.25	173.65
300	18.75	80.25	185.80
350	22.30	88.30	197.65
400	27.20	94.55	235.43
450	34.75	101.44	286.88

500	41.80	109.15	328.95
550	56.40	116.35	355.67
600	64.20	150.45	412.75
650	78.60	227.35	532.42
700	90.30	291.05	600.45
750	100.42	347.35	755.20
800	108.30	502.65	900.45

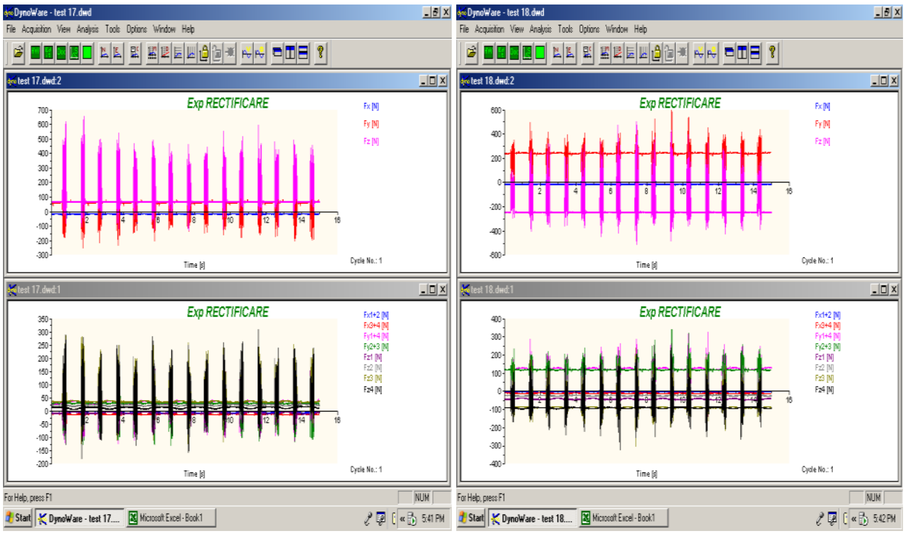


Fig. 6.22. Measured values of cutting forces on processing using a worn grinding wheel.

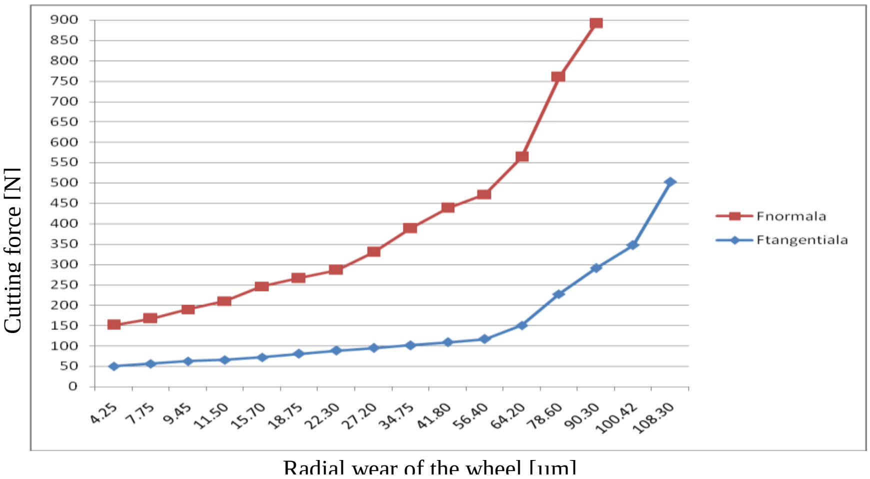


Fig. 6.23. Variation of the cutting force components in relation to the radial wear of the grinding wheel

It can be observed that the tangent force, as well as the normal force, increase exponentially with the increase of wear in the grinding wheel. The tangent force increases more slowly compared to the normal force, whose increase is more significant.

Conclusions:

- Independent parameters, depth of cut, degree of wear on the radius of the grinding wheel and the cutting speed influence F_t as well as F_n.
- For the constant speed of 36 m/s and an increase of feed from 0.15 mm/troke to 0.25 mm/troke, there is an increase in the normal and tangent components of the cutting force

- At the constant speed of 50 m/s and at the same variation of feed from low values to high values, an increase in the normal and tangent components is observed.
- When the depth of cut increases from 0.01 mm to 0.03 mm, the normal and tangent forces increase due to the thickness of the undistorted chip.
- Experiments have shown that if only the feed increases, the increase gradient of the forces is low.
- At high speeds and small feeds, the force decreases.
- The wear of the grinding wheel significantly influences the values of the components of the grinding force.
- Knowing the way in which the parameters of the cutting mode influence the size of the forces, this process parameter can be controlled. Cutting modes with small feeds and high speeds are recommended.

6.5. The study of temperature in the grinding process of DK460UF carbide

6.5.1. The study of temperature using INFRARED CAMERAS

In figure 6.25., images show the increase of temperature in the contact area at the same time with the increase of cutting speed. Upon increasing the cutting speed, at a constant depth, the variation of temperature flow is significant.

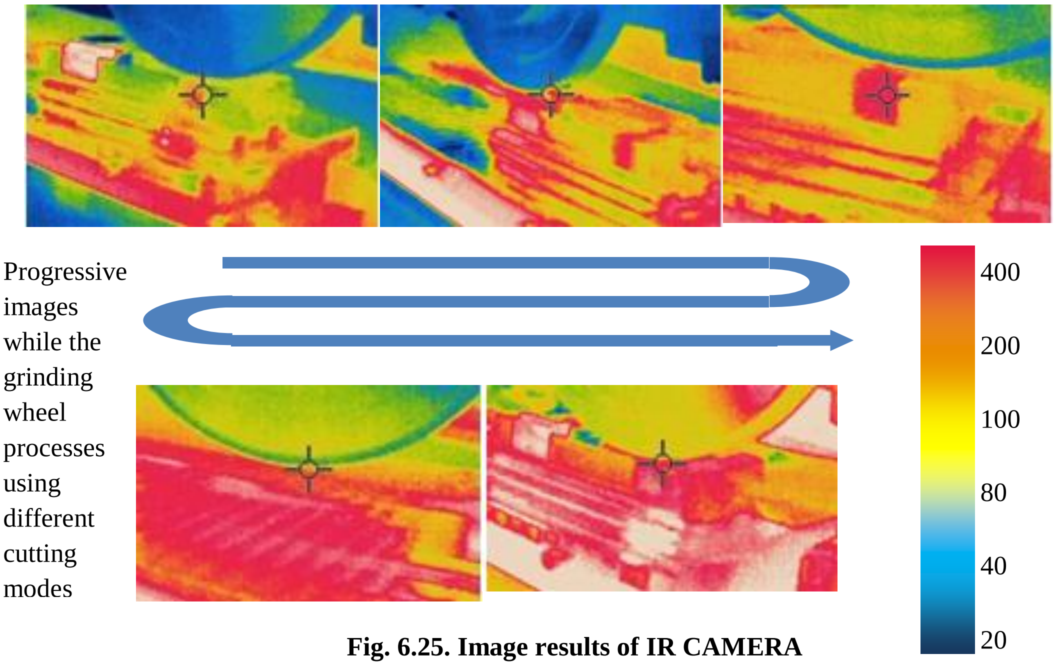


Fig. 6.25. Image results of IR CAMERA

6.5.2. The study of temperature when grinding DK460UF carbide using natural thermocouple

Fig. 6.27. Stall for the calibration of the thermocouple

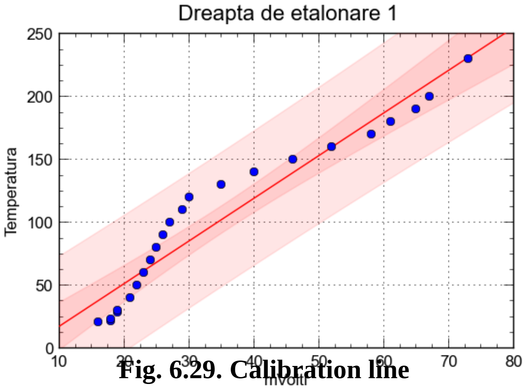


Fig. 6.29. Calibration line

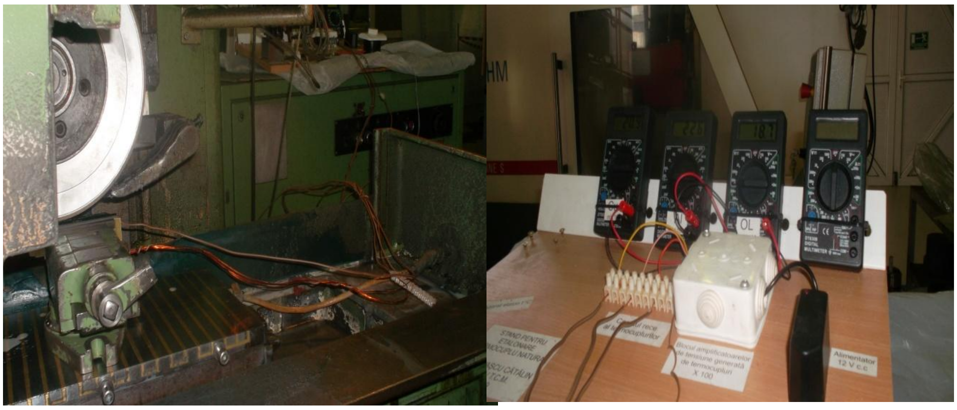


Fig. 6.30. Installation for measuring with a K type thermocouple

The results of the measurements are presented in the table below:

Table 6.6

No.	Speed v [m/s]	Feed f [mm/rot]	Depth of cut a_p [mm]	Tension U [mV]	Temperature T $[^0C]$
1.	25	0.15	0.015	30.1	174
2.	25	0.15	0.025	52.6	310
3.	25	0.25	0.015	42.7	260
4.	25	0.25	0.025	53.5	325
5.	40	0.15	0.015	33.6	200
6.	40	0.15	0.025	57.8	350
7.	40	0.25	0.015	37.4	240
8.	40	0.25	0.025	67.8	480

Mathematical model

$$T = -114.62393 + 5.91106 * v + 390.67935 * f + 5841.43702 * a_p \quad (6.18)$$

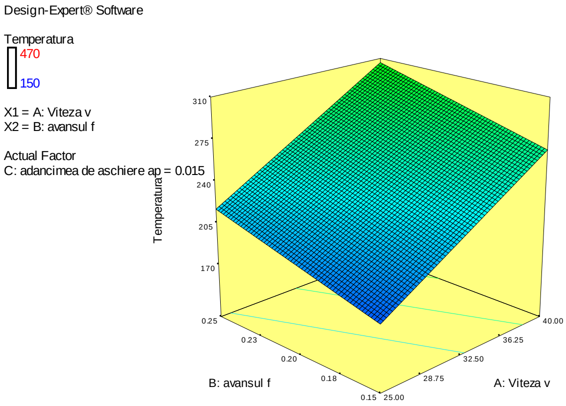


Fig. 6.32. Variation of temperature in relation to v and f
a_p =0.015mm

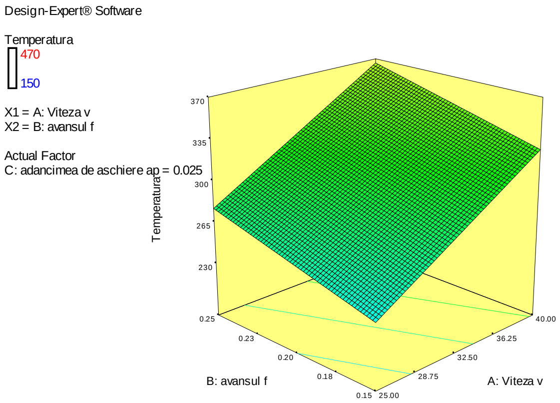


Fig. 6.33. Variation of temperature in relation to v and f
a_p =0.025mm

6.5.3. Conclusions

- The independent parameters, depth of cut, feed and cutting speed influence the quantity of heat generated during processing.
- The influence of cutting speed on temperature is significant in relation to other parameters. Thus, the increase of temperature in relation to the increase of speed is greater at a higher feed and the increase is lower if the feed is lower.
- In the field of ordinary speeds, due to the increase of temperature in the plastic area, material adherences disappear or are diminished and the level of forces is reduced due to the reduction of distortions and frictions.
- The increase of temperature is also determined by the wear of the grinding wheel and can be considered an indirect indicator of wear.
- It is important to know the grinding temperature in evaluating the physical – chemical state of the processed surface, but also that of the subprocessed layer.
- On the other hand, by knowing the way in which the cutting mode parameters influence the quantity of heat, this process parameter can be controlled.

6.6. The wear of the grinding wheel when processing DK460UF carbide

The experiment aims to study the wear of the grinding wheel with different grits according to the number of processed marks and the volume of the removed material. Also, a study should be conducted regarding the wear of the grinding wheel in relation to the volume of the removed material.

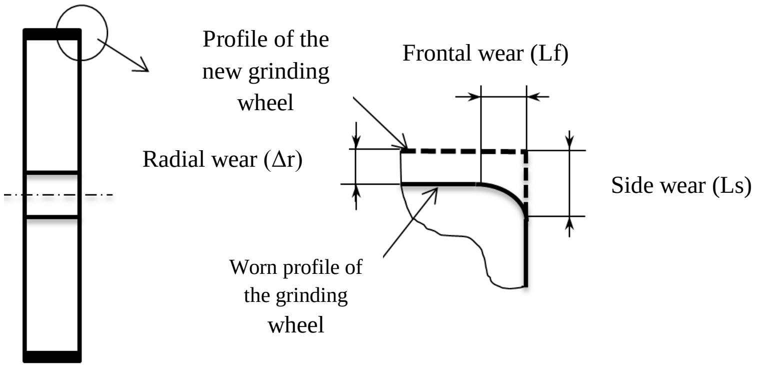


Fig. 6.39. Estimated parameters of the wear of the grinding wheel

The main parameters that estimate the wear of the grinding wheel are presented in figure 6.39.:

- radial wear (Δr);
- corner wear.

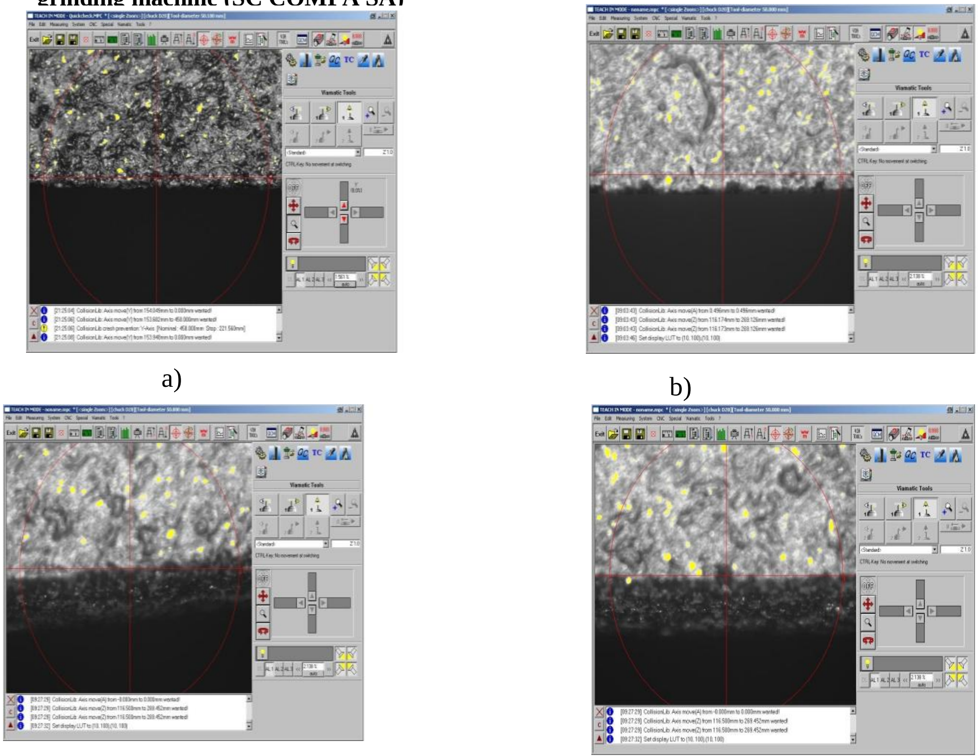
6.6.1. Planning the experiment

The grinding wheel wear was monitored during the cutting process of drills for deep holes with small diameters (2.025 - 2.5 mm). The drills were sharpened on a Walter Helitronic Minipower machine tool. (fig. 6.31.)

Each drill was processed on 5 different surfaces, to obtain the active surface. Grinding wheels with 46 µm and 54 µm grit were used for processing.

Fig. 6.40. Walter Helitronic Minipower grinding machine (SC COMPA SA)

Fig. 6.41. Walter Helicheck Basic Optical CNC (SC COMPA SA)



a)

b)

c)

d)

Fig. 6.42. Surface and profile of the D54 grinding wheel after process a:
a) 100 drills b) 200 drills c) 300 drills d) 400 drills

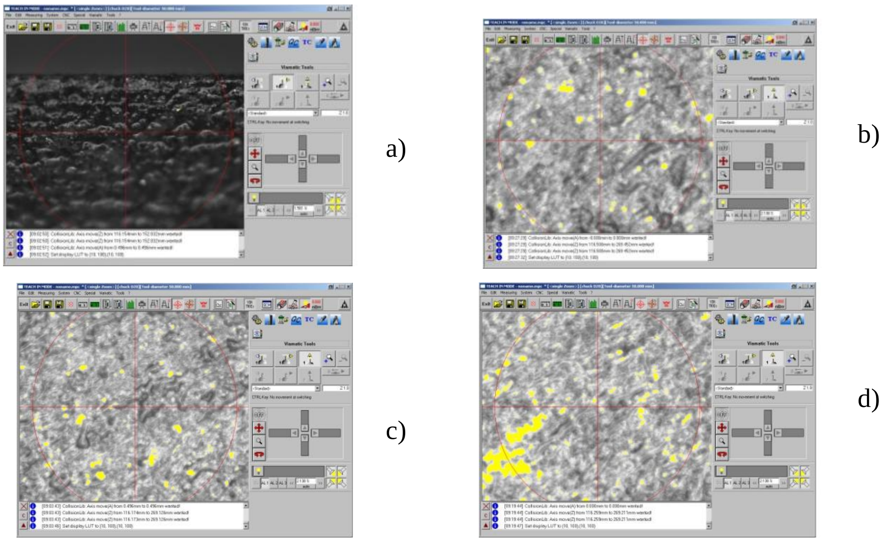


Fig. 6.43. Evolution of dislocation for the D54 grinding wheel after process a:
a) new wheel b) 200 drills c) 400 drills d) 600 drills

Figure 6.43. shows that if the wear of the profile increases, the number of dislocations increases as well (grinding diamond granules leave the grinding wheel – light spots in the image).

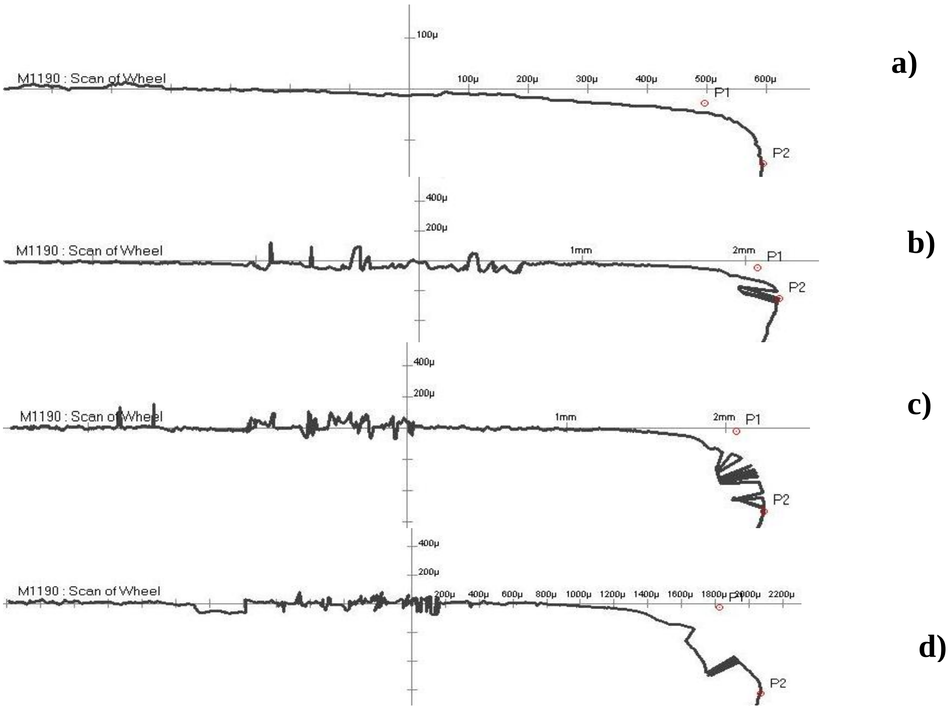


Fig. 6.44. The wear of the grinding wheel with 54 µm grit: *a) – the profile of a new wheel; b) – the profile of the wheel after it has sharpened 300 drills; c) - the profile of the wheel after it has sharpened 600 drills; d) - the profile of the wheel after it has sharpened 800 drills*

6.6.2. Conducting the experiment

To measure the wear of the profile of grinding wheels, these were monitored using samples of 100 benchmarks. The Walter Helicheck Basic Optical CNC measuring machine was used for measuring results (fig.6.32).

6.6.3. Processing the experimental data

The wear of the grinding wheel profile was measured after processing a batch of 100 drills. Catastrophic wear occurred when the radial wear was 0,1 mm.

Table 6.7.

Number of sharpened drills for deep holes with a small diameter|	Volume of removed material [mm^3]	Radial wear of the cutting wheel with a 46 µm grit (Δr) [µm]	Radial wear of the grinding wheel with a 54 µm grit (Δr) [µm]	Profile wear of the grinding wheel with a 46 µm grit [µm]	Profile wear of the grinding wheel with a 54 µm grit [µm]
0		0.00	0.00	0	0
100	102	5.24	7.75	27.04	32.56
200	204	8.30	11.50	43.16	43.52
300	306	16.34	21.75	115.23	92.53
400	408	28.56	32.20	167.81	138.56
500	510	43.12	48.80	224.57	227.82
600	612	54.76	64.20	281.32	337.86
700	714	68.05	90.30	351.71	469.63
800	816	79.37	115.00	408.73	587.79
900	918	93.17		482.52	
1100	1122	112.4		568.34	

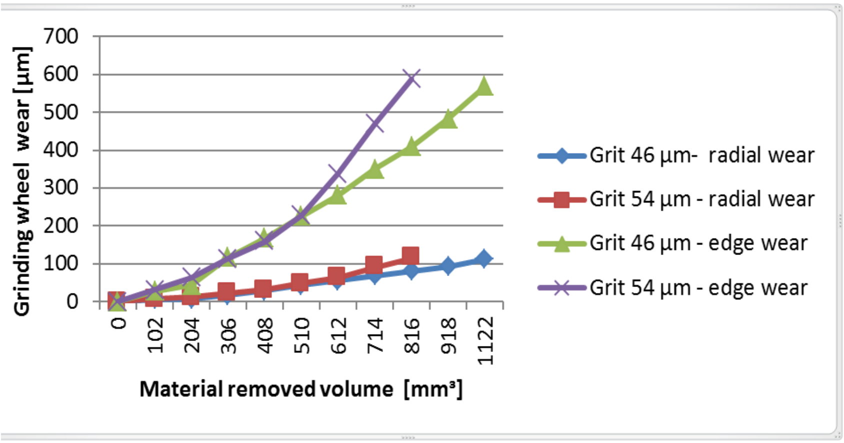


Fig. 6.45. Variation of radial and profile wear for grinding wheels with different grits

Figure 6.46. represents the ”G-ratio” variation in relation to the volume of removed material during the grinding process using wheels of different grits. "G-ratio" values are generally very low, which demonstrates that the processing of these wolfram carbide tools is more difficult than grinding extended areas.

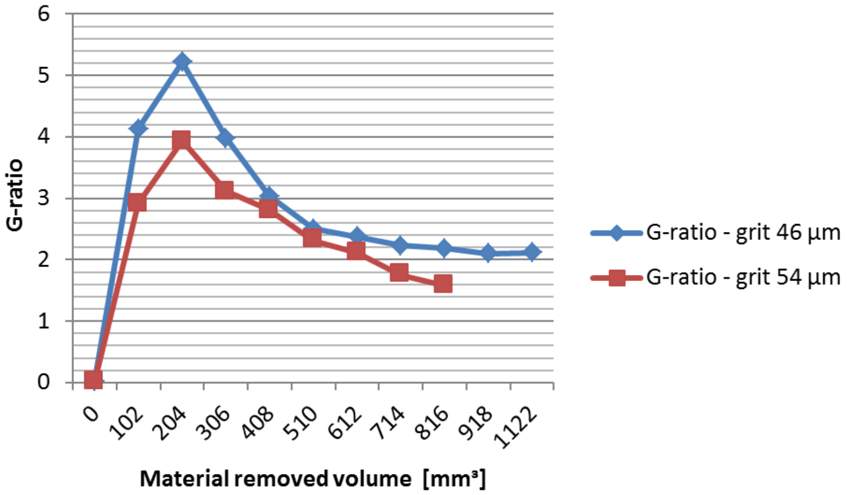


Fig. 6.46. "G-ratio" variation in relation to the volume of material removed when processing with grinding wheels of different grits

Figure 6.47. a) presents the structure of a new D 46 grinding wheel, b) is the structure of the same wheel with a radial wear of 43.12 µm.

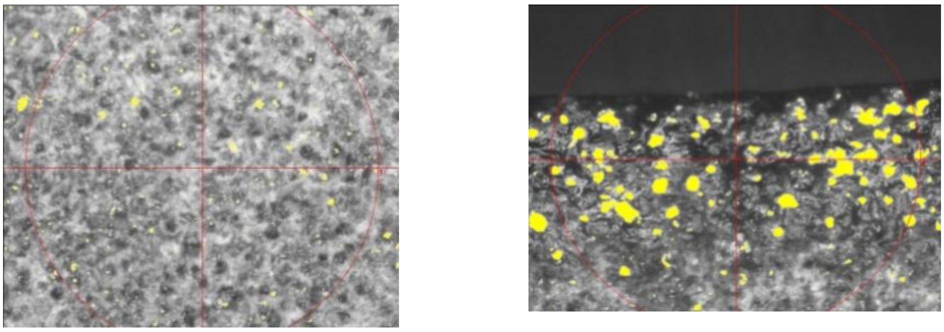


Fig. 6.47. – Structure of the grinding wheel: *a) the grinding wheel before use b) the grinding wheel with a radial wear of 43.12µm (SEM image 1500 x zoom)*

6.6.4. Conclusions

The study conducted on the wear of the grinding wheel has the following conclusions:

- By analyzing the wear curves, we can observe that grinding wheels with a greater grit wear off faster.
- The performance of the grinding wheel features a greater value of the ”G-ratio”. Due to the small surfaces of drills for deep holes with a small diameter, with lots of edges and gaps, a hypothesis for the study can be drawn: ”G-ratio” is low.
- The study shows that ”G-ratio” decreases relative to the wear of the grinding wheel.
- Processing small surfaces with cutting edges and gaps is difficult compared to larger surfaces. The grinding wheels sustain shocks which lead increase their wear.
- From the point of view of grit, ”G-ratio” is greater when using low grit wheels, which implies a more efficient process. Low grit wheels are preffered when processing drills for deep holes with small diameter.

6.7. Measuring surface roughness

6.7.1. Defining the object of research

To determine the roughness of the surface processed by grinding DK460UF carbide used in manufacturing drills for deep holes of a small diameters, we seek to obtain an experimental model. Following the preliminary analysis, modelling by complete factorial experiment, type tipul 2^4, was chosen.

The objective functions are R_z, R_a.

6.7.2. Planning the experiment

Processing the rectangular samples of DK460UF metal carbide, of 20 x 50 x 100 mm sizes was performed on a numerical on a CNC HAWEMAT 3000 machine (fig.6.48.), with grinding wheels of different grits, 46 μm, 56 μm respectively, of 150 mm and 180 mm diameters, of 10 mm width. A water and oil emulsion of 5%, PETROFERSUPERFIN, was used as a cooling medium at a 1 MPa pressure, suited for the superior quality of the surfaces processed with diamond grinding wheels.

Fig. 6.48. CNC HAWEMAT 3000 (GUHRING SRL)

Fig. 6.49. ***MITUTOYO*** **roughness tester**

Table 6.9. Levels of variation of the factors

Parameter		Values	
Real	Codified	Levels	
		- 1	**+ 1**
Cutting speed, v [m/s]	X_1	40	55
feed, f [mm/rot]	X_2	0,005	0,008
Depth of cut, a_p [mm]	X_3	0,01	0,03
grit [µm]	X_4	46	54

The program-matrix of 2^4 factorial experiment is created using the Design Expert software.

Tabelul 6.10. The program-matrix of 2^4 factorial experiment

Nr.	Grinding wheel grit [µm]	Speed v [m/s]	Feed f [mm/rot]	Depth of cut a_p [mm]	Roughness R_a [µm]	Roughness R_z [µm]
1	46	40	0.005	0.03	0.126	0.504
2	46	55	0.005	0.03	0.113	0.452
3.	46	40	0.008	0.03	0.142	0.568
4.	46	55	0.008	0.03	0.132	0.532
5.	46	40	0.005	0.01	0.063	0.290
6.	46	55	0.005	0.01	0.057	0.228
7.	46	40	0.008	0.01	0.084	0.328
8.	46	55	0.008	0.01	0.077	0.316
9.	54	40	0.005	0.03	0.139	0.572
10	54	55	0.005	0.03	0.128	0.512
11	54	40	0.008	0.03	0.156	0.645
12	54	55	0.008	0.03	0.150	0.597
13	54	40	0.005	0.01	0.072	0.342
14	54	55	0.005	0.01	0.065	0.276
15	54	40	0.008	0.01	0.095	0.381
16	54	55	0.008	0.01	0.087	0.362

By applying the multiple polynomial regression, the expression for evaluating roughness was obtained, with

$$R_a = -0.0484 + 3.0375 \cdot a_p + 6.6667 \cdot f + 1.5313 \cdot 10^{-3} grit - 5.6667 \cdot 10^{-4} \cdot v \quad (6.21)$$

$$R_z = -0.2179 + 11.98 \cdot a_p + 20.625 \cdot f + 8.047 \cdot 10^{-3} grit - 2.54 \cdot 10^{-3} \cdot v \quad (6.22)$$

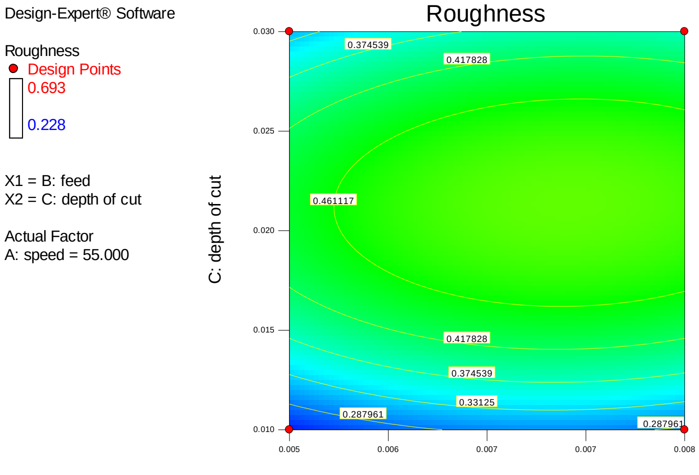


Fig. 6.57. Variation of roughness in relation to f, a_p
v = 55 m/s (D46VB4P/A)

From the point of view of the appearance of the processed surface, it was visualized using an electronic microscope. The images captured with the electronic microscope complement the results obtained by performing measurements.

**Fig. 6.64. Electronic microscope (Institut Français de Mécanique Avancée-
Laboratoire Casimir)**

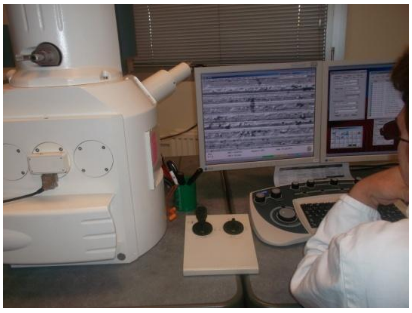
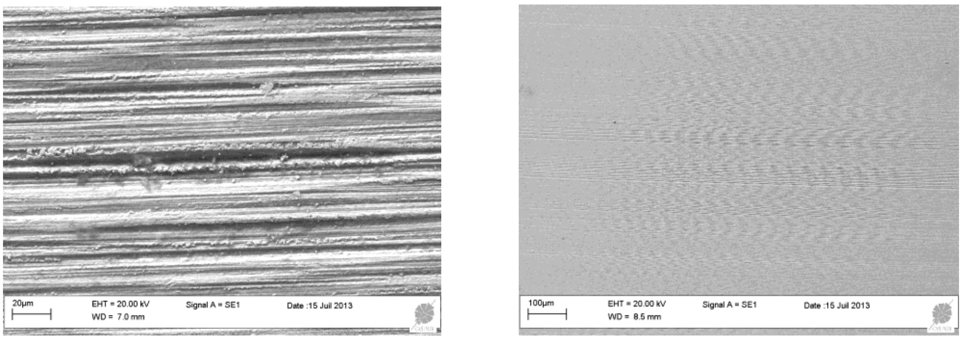


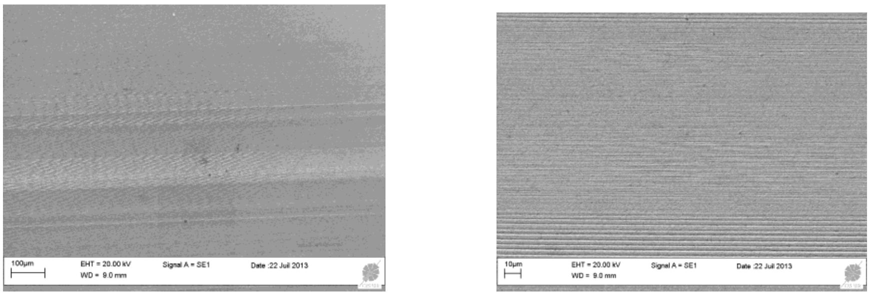
Fig. 6.67. Image capturing



a) Surface before processing

b) Processed surface v=55m/s, f=0.005 mm/rot, a_p = 0.01mm

Fig. 6.68. SEM images of surfaces processed with D46VB4P/A grinding wheel



a) Surface before processing

b) Processed surface v=55m/s, f=0.005 mm/rot, a_p=0.01mm

Fig. 6.69. SEM images of surfaces processed with D54P150/A-C100 grinding wheel

6.7.3. Conducting the experiment

During the experimental research, attempts were made in which the parameters of the cutting mode and the grits had as variation fields:

- cutting speed, v = 40 ÷ 60 [m/s]
- feed, f = 0,005 ÷ 0,008 [mm / rot]
- depth of cut, a_p = 0,01 ÷ 0,03 [mm]
- grit from 46 µm to 54 µm

6.7.4. Variation of roughness in relation to the wear of the grinding wheel

Roughness is influenced by the wear of the grinding wheel. For this study, the optimal cutting mode is considered in the case of processing using new grinding wheels, thus: cutting speed v = 55 m/s, feed f = 0.005 mm/rot and a depth of cut a_p = 0.01 mm.

Tabelul 6.11. Grinding wheel radial wear
(cutting regime: depth of cut = 0.015 mm, feed = 0.005 mm/rev, speed = 55 m/s)

Number of sharpened gundrills	Grinding wheel with 46μm grit		Grinding wheel with 54μm grit	
	Radial wear [μm]	Roughness R_z [μm]	Radial wear [μm]	Roughness R_z [μm]
0	0.00	0.228	0.00	0.423
100	5.24	0.236	7.75	0.435
200	8.30	0.248	11.50	0.468
300	16.34	0.321	21.75	0.520
400	28.56	0.393	32.20	0.668
500	43.12	0.471	48.80	0.814
600	54.76	0.625	64.20	1.054
700	68.05	0.768	90.30	1.192
800	79.37	0.873	115.00	1.370
900	93.17	0.987		
1100	112.4	1.068		

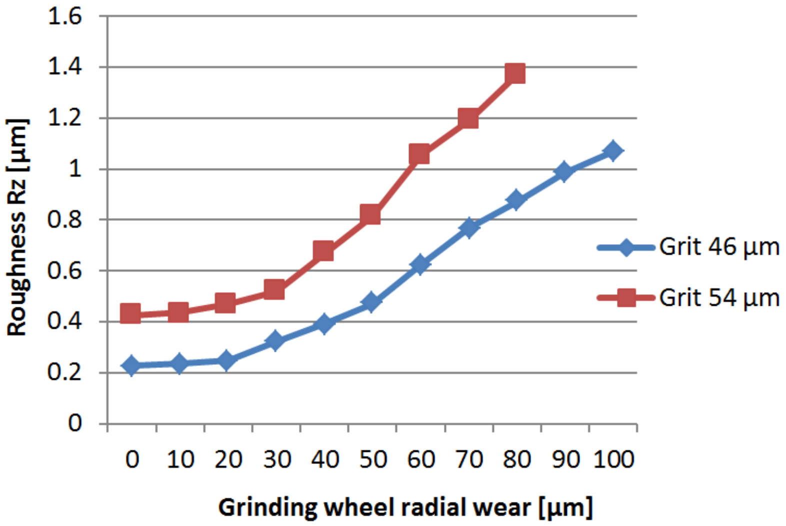
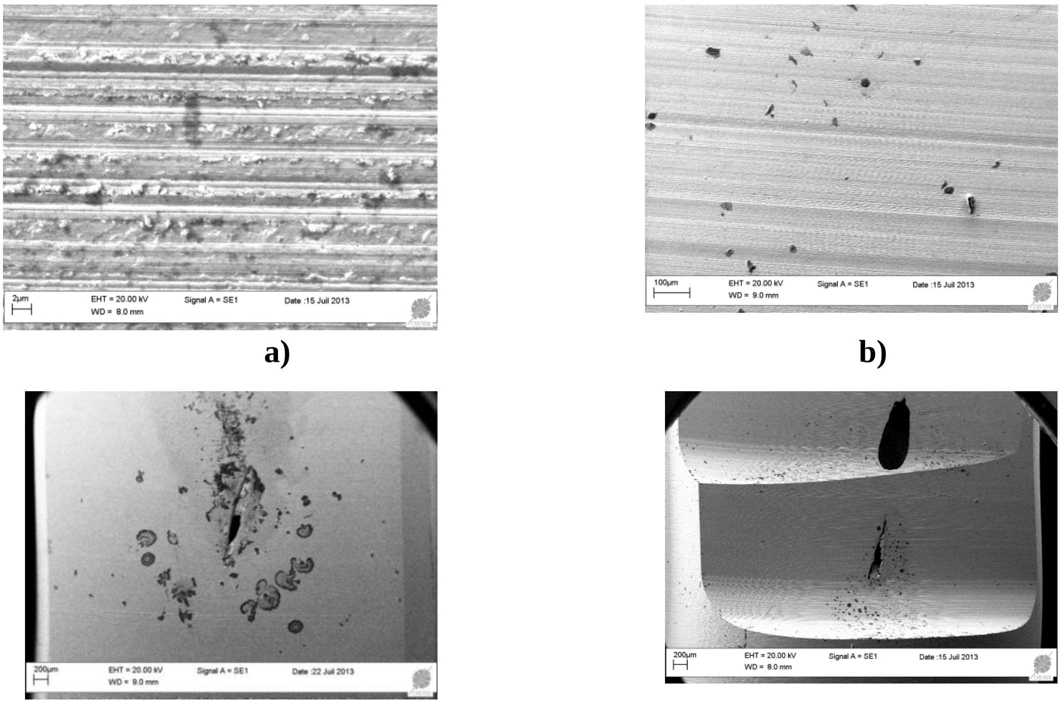


Fig. 6.70. Variation of roughness in relation to the radial wear of the grinding wheel

Surfaces processed with worn grinding wheels were also examined under the electronic microscope. Images captured using SEM are presented in figure 6.62. It can be observed that each type of wear of the wheel creates major defects of the processed surfaces.



a) b)

c) d)

Fig. 6.71. Surfaces processed with worn grinding wheels:

a) *Grinding with D46VB4P/A grinding wheel with 46 µm grit, with a radial wear of Δr = 34.75 µm,* a_p*=0.03 mm, f=0.008 mm/rev, v=55m/s, roughness* R_z *= 1.192 µm. Radial wear caused greater roughness.*

b) *Grinding with D46VB4P/A grinding wheel with 46 µm grit, clogged,*a_p*=0.01mm,f=0.005 mm/rev,v=40m/s, roughness* R_z *= 0.972 µm. The clogging of the grinding wheel determines the adherence of the material particles to the processed surface.*

c) *Grinding with D54VB4P/A grinding wheel with 54 µm grit, worn granules,* a_p*=0.03mm, f=0.008 mm/rev, v=55m/s, roughness* R_z *= 0.768 µm. Due to the wear of the grinding wheel, there is intense friction between the surface and the wheel, which causes an increase in temperature in the contact area. The layer under the processed surface shows burns and oxidations.*

d) *Grinding with D54VB4P/A grinding wheel of 54 µm grit, clogged,* a_p*=0.03mm, f=0.008 mm/rev, v=40m/s, roughness* R_z *= 0.766 µm. The material particles adhere to the processed surface.*

Conclusions:

- Independent parameters, depth of cut, feed, grit and cutting speed influence R_z and R_a.
- Roughness increases in relation to the increase of the depth of cut. Roughness may be decreased if the depth of cut is reduced when grinding wheels with low grits are used.
- The feed is very important in influencing the surface roughness when grinding wheels with high grits are used. Using low grit grinding wheels decreases the significance of this parameter.
- Grit significantly influences the roughness of a surface. High grits of grinding wheels determine high values of surface roughness. Since the granules are large and the distance between them is greater, this causes an increase of the cross-sectional area of the removed chip.
- The cutting speed has a relatively small effect on the values of roughness. The increase in speed causes a slight decrease of the values of roughness.
- It is important to optimize the grinding process of the wolfram carbide used for cutting tools, because their active surfaces require certain qualitative features. Moreover, the quality of the active surface of the cutting tool leads to an easier

removal of the chips and thus durability is improved. The maximum roughness permitted for the active surface is Rz = 0,3µm.

- The experimental results facilitate the achievement of optimum parameters for the grinding process from the point of view of surface quality. The optimum parameters resulting from the experimental research of the grinding process were: depth of cut ap = 0,01 mm, feed f = 0,005 mm / rot, cutting speed v = 55 m/s, grit of grinding wheel 46 µm. In these conditions, the value of surface roughness is Rz = 0.228 µm.
- The study of roughness variation in relation to the radial wear of the grinding wheel, with the imposed roughness Rz = 0,3 µm, concluded that it can only be achieved by processing using grinding wheels of grits lower than 46 µm. In this case, for D46, a maximum radial wear of Δr = 30 µm is allowed.

7. GENERAL CONCLUSIONS, PERSONAL CONTRIBUTIONS AND FUTURE LINES OF RESEARCH

In this doctoral thesis, the study of the grinding process for DK460UF metal carbide was conducted, used in manufacturing tools for machining holes, in order to determine the optimal processing parameters.

7.1. General conclusions

The grinding process is a process of machining that includes several factors that more or less have an influence on its proper execution. The optimization of the machining grinding process may be achieved by partially optimizing its components.

- Grinding wheels with diamond granules and resin-based binder are recommended for processing metal carbides. It has been demonstrated that grinding wheels with gross grit lead to an increase of specific energy and of the quantity of removed material, to the expense of the quality of the processed surface.
- The factors that have an impact on the quality of the surface processed by grinding are: the grinding wheel, the parameters of the cutting mode, the cutting medium, the cutting forces, the temperature flow.
- The analysis of factors that influence the quality of the surface processed by grinding show the fact that the parameters of the cutting regime have a great impact on its improvement, alongside the features of the grinding wheel.
- The active surfaces of drills for deep holes with a small diameter, with cutting edges and holes for the cooling liquid require a superior quality. The parameters of the cutting regime, the properties of the grinding wheel and the degree of wear are subjects of the present study. The creation of models for forces, temperatures, wear of the grinding wheel and roughness are useful results in the field of processing metal carbides.
- The grinding force depends on the feed, speed, the depth of cut and the velocity. Also, the degree of wear of the grinding wheel has an influence on the sizes of forces.
- The cutting speed influences the components of the cutting forces, but the degree of influence of the main speed also depends on the values that other parameters of the cutting process acquire. Thus, for a constant speed of 36 m/s, and an increase of the feed from 0.15 mm/stroke to 0.25 mm/stroke, an increase in the normal and tangent components of the cutting force is detected, due to the greater thickness of the undistorted chip. Also, at a higher, constant cutting speed, the grinding force increases as the feed between the same limits increases, the cutting process is intensified, but due to the high cutting speed, friction also increases.
- When the depth of cut is increased from 0.01 mm to 0.03 mm, the normal and tangent forces increase due to an increase in the thickness of the undistorted chip.
- By knowing the influence that the cutting mode parameters have on the grinding force, this factor can be controlled.

- It has been observed that when the feed is low and the cutting speed is high, the forces decrease.
- The wear of the grinding wheel determines an increase of the grinding force.
- Higher grit grinding wheels wear off faster.
- The ”G-ratio” parameter, indicator of volumetric wear of the cutting wheel, in materials that are hard to process when working under difficult conditions, may decrease.
- Processing of small surfaces with cutting edges and gaps is difficult compared to larger surfaces. The grinding wheels are subjected to shocks, which leads to significant wear.
- The ”G-ratio” is greater when using wheels of lower grit, which implies a more efficient process. Low grit wheels are preferred when processing the surface of drills for deep holes with a small diameter.
- The wear of the grinding wheel is also influenced by the parameters of the cutting regime and by the cutting medium At a greater depth of cut, the cutting force on the grinding grain is higher, which results in an increase of wear. At high cutting speeds, the friction between the grinding wheel and the surface to be processed is greater, leading to the wear of the grains. The temperature in the grinding process determines the wear of the grinding wheel. The rate of wear of the grinding wheel is decreased by using a cooling medium.
- The maximum temperature in the contact area increases with the increase of the depth of cut, with the speed of the wheel, with the wheel diameter, but it decreases with the speed of the piece.
- The quantity of heat in the piece depends on the cutting regime parameters.
- The overall temperature is harmful to the processed layer, while the local temperature and the heat generated in the contact area between the grain and the processed surface determine an increase in the degree of wear of grinding grain.
- The average temperature decreases as the speed of the piece increases because heat is always retrieved by new areas of the piece.
- The wear of the grinding wheel determines an increase of temperature.
- The depth of cut parameter has the greatest influence on the roughness of DK460UF processed surfaces by grinding. If it decreases from 0,03 to 0,01 mm, the roughness of the surface is approximately 50% improved (R_a decreases from 0,113 μm to 0,057 μm and R_z decreases from 0,452 μm to 0,228 μm).
- Feed is the second most important factor in influencing roughness. The decrease in feed leads to a decrease in roughness.
- Grit of the grinding wheel influences the quality of the surface. A wheel with fine grit will lead to a smaller value of roughness.
- The cutting speed has a relatively small influence. The increase in speed slightly decreases roughness.

The mathematical models obtained for roughness are robust and important. The complex statistical analysis conducted using Design Expert software has proven the adequacy of the model and the chance that the roughness value would change in the case of random noise is 0,01%.

7.2. Personal contributions

Personal contributions are reflected in:

1. Elaboration of the SWOT analysis to determine the opportunities of the subject presented in the doctoral thesis.
2. An extensive bibliographical research that has included a large number of papers that have approached the issue of grinding processing (over 500 papers, out of which 30% were published in the past 5 years. I have summarized the information from these papers in

table form - tables 2.2., 2.3 and 2.4., in which the analyses conducted by researchers and their results were presented. The fields of research are: materials processed through grinding, the structure and topography of the grinding wheel and the influence of these aspects on the process, as well as phenomena accompanying the grinding process).

3. The structured presentation of all aspects related to the grinding process: the grinding wheel, grinding kinematics (chip formation, grinding forces, necessary movements), the cutting mode, the cutting medium.

4. A summarized presentation of modelling techniques and of models for important aspects of the grinding process.

5. Elaboration of the general analysis model for the grinding processing of DK460UF metal carbide.

6. Establishing the influence of different process factors and ranking them using the ”Triple cross” technique.

7. Elaboration of a numerical model of the heat flow when processing DK460UF metal carbide.

8. Presentation of drills for deep holes of small diameters, of their geometric features, of the problems that appear in the exploitation process (deep drilling).

9. Designing the manufacturing technology of drills for deep holes with small diameters, with emphasis on the grinding operation.

10. Establishing experimental research to identify and define the work parameters for grinding DK460UF carbide used in manufacturing cutting tools for processing holes.

11. Planning the experiments to determine the influence of grinding processing parameters in the grinding force, conducting the experiments, analysis and interpretation of results. To determine the mathematical models and the graphical representation of its dependency on independent variables the Design Expert software was used. The adequacy of the model and determining the impact of influencing factors on the grinding force were performed using the ANOVA statistical analysis method.

12. Planning the experiments to determine the influence of grinding process parameters on temperature, conducting the experiments, analysis and interpretation of results. For measuring, a carbide-copper thermocouple was used, and as a calibrator, a type-K thermocouple. A calibration stand was used to calibrate the thermocouple. To determine the mathematical models and the graphical representation of its dependency on independent variables, the Design Expert software was used. The adequacy of the model and determining the impact of influencing factors on temperature were performed using the ANOVA statistical analysis method. To visualize the intensity of temperature flow in the contact area between the grinding wheel and the carbide surface, INFRARED CAMERAS were used.

13. Planning the experiments to determine the wear of the grinding wheel in relation to the number of processed benchmarks (drills for deep holes with small diameters). The evolution in the wear of the grinding wheel was monitored, measuring the radial wear at each 100 processed benchmarks, determining the number of benchmarks at which catastrophic wear occurs. It was processed 1900 gundrills for two grinding wheels (for grinding wheel with 46 μm, the catastrophic wear occurs after 1100 machined gundrill and for grinding wheel with 54 μm, the catastrophic wear occurs after 800 machined gundrill).

14. Planning the experiments for determining the influence of grinding process parameters on the roughness of the processed surface, conducting the experiments, analyzing and interpreting the results. To determine the mathematical models and the graphic representation of its dependency on independent variables, the Design Expert software was used. The adequacy of the model and determining the impact of influencing factors on roughness were performed using the ANOVA statistical analysis method.

15. Using SEM to visualize the impact of cutting mode parameters and the properties of the grinding wheel on the quality of the processed surface. The study was conducted at the French Institute of Advanced Mechanics in Clermont Ferrand, Franța.

16. Conclusions regarding the optimal processing parameters for DK460UF metal carbide, with a 91% WC and 9 % Co content, processed using two different types of grinding wheels, with different grits, 46 μm and 54 μm. The processing conditions for reaching the 0,228 μm roughness threshold imposed by the surface quality were determined:

- Using low grit wheels (46 μm) in the following cutting mode: cutting speed 55 m/s, feed 0,005 mm/rev, and 0,01 mm depth of cut.

For the obtained values of the cutting mode, the other factors involved in the grinding process also fall within the influence limits that do not significantly alter the quality of the active surfaces of deep hole drills, which is extremely important for conducting an advanced process of deep drilling.

7.3. Future lines of research

Subsequent to the research conducted within the present doctoral thesis, it is useful to develop studies on the following subjects:

1. Determining the dependency of the quality of active surfaces of drills for deep holes with a small diameter made of DK460UF metal carbide, processed through grinding, on other factors, such as: the contact duration between the grinding wheel and the surface to be processed, the geometry of the chip, the topography of the grinding wheel, etc.

2. Determining the influence of processing parameters on the quality of processed surfaces for other types of drill.

3. Using other methods to determine the optimal parameters for the grinding processing of DK460UF carbide, such as: the Taguchi method, etc.

4. Creating a database containing all the optimal parameters for processing wolfram carbide destined for the manufacturing of cutting tools to process deep holes of small diameters, as well as the optimal combination of these parameters.

5. Creating an advanced system for measuring temperature in the contact area

6. Creating an overall monitoring system for the process of grinding metal carbides. Currently, certain parameters are optimized and according to them, other parameters will be improved.

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