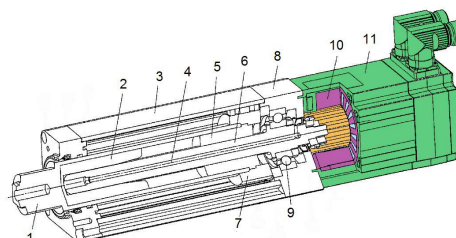


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Evolution of spindle assemblies of machines based on motor-spindle

Yurii Kuznietsov, Kateryna Oliinyk

National Technical University of Ukraine "Igor Sikorsky Kyiv Politechnic Institute"

Abstract. Solving the problems caused by the growth of M-S diversity belongs to the latest current scientific field of research in modern mechanics and electromechanics, which is generalized to the concept of structural and systems research with models of microevolution and macroevolution. If genetic synthesis allows to find new structures of M-S and spindle nodes on their basis, then for the synthesis of schemes and structures it is advisable to use a system-morphological approach. To develop a morphological model, functional (morphological) features are selected, which are divided into three groups in accordance with the modular principle: the modules of the rotational motion of the spindle, the drive feed -translational motion and the clamp-expansion.

KEY WORDS: MACHINE, MAIN DRIVE, MOTOR-SPINDLE, INTELLIGENT SPINDLE, EVOLUTIONARY SYNTHESIS, GENETIC OPERATORS, MORPHOLOGICAL MODEL

1. Current trends and restraining factors of high-speed metalworking.

In the context of the challenges of "Industry 4.0" and the approach of "Industry 5.0", one of the relevant topics in modern engineering technology is High Speed Cutting, High Production Cutting and High Precision Cutting [2]. Fast, high-quality and cheap - these are the advantages of advanced processing, which is widely implemented in enterprises of mechanical engineering, automotive, aircraft and others using advanced cutting tools that can increase many times (10-15 times) the speed of cutting and feeding on CNC machines. Already today there is a need to use lathes with a spindle speed (for workpieces) up to 20 thousand rpm., Drilling and milling up to 200 thousand rpm. and more. At such speeds (centrifugal forces increase squarely depending on the speed) dynamic loads reach catastrophic values, which requires changing the priorities of the requirements for spindle assemblies, clamping mechanisms of the workpieces, the clamping chuck in terms of reliability, accuracy and safety. High-speed machining requires the creation of new designs of spindle assemblies, high-speed clamping chucks with compensation of centrifugal forces), the use of new high-strength and vibration-resistant materials for body parts, balancing and mechatronic devices and more. In the drive of the main movement of high-speed lathes with $n_{max} > 10$ thousand rpm. it is almost impossible to use electric motors with mechanical reduction. Therefore, machines designed for high-speed machining are equipped with new aggregate-modular designs of spindles with special supports (bearings) and built-in electric motors such as motor-spindle (M-S) [3,8,9].

One of the main indicators of technical and economic efficiency of metalworking is the cost, which has such an important characteristic as the productivity of the cutting process [1,10]. Depending on the approach to the evaluation of the cutting process, the productivity of turning can be expressed by different values and, in particular, through the volume productivity, m^3 / min , it is seen that the increase in machining productivity is influenced by the speed (speed of rotation of the part), feed and depth of cut. Accuracy of manufacturing of details which is provided at finishing operations, is also one of the most important characteristics of quality and is characterized by stability of the sizes, deviations of a geometrical form, undulation and roughness of a surface. If, for example, we talk about the roughness of the surface of the part during turning, the significant influence is exerted by the cutting speed (v), feed and geometry of the cutter. Height of irregularities depending on giving and radius of rounding of the cutter: (2) Thus, on the one hand, to increase the technical and economic performance of machines on finishing operations, it is necessary to increase the cutting speed (speed of the part n) and reduce the feed, while increasing the productivity and quality of the treated surface. At the same time normal conditions of processing from the point of view of observance of safety measures have to be provided. Improving the speed of SW lathes is constrained by a number of factors, among which are the following (Fig. 1):

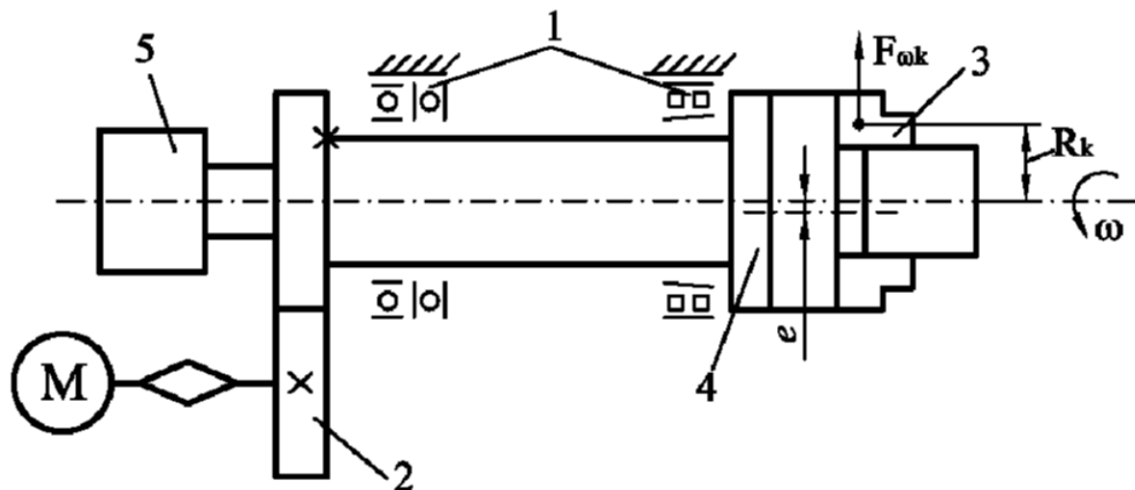


Fig. 1. Spindle assembly of the lathe with designation of sources-places of restriction of frequency of rotation: 1 - support; 2 - transfer of turns on a spindle from the engine; 3 - clamping chuck with radius R_k of unbalanced clamping elements; 4 - system "spindle-chuck-part" with eccentricity (imbalance) e ; 5 - clamp drive

1) spindle supports, characterized by speed (n - maximum spindle speed, rpm; d - average diameter of spindle necks for bearings, mm); according to this indicator, all spindle units on the rolling bearings are divided into low-speed, medium-speed and high-speed [1,4];

2) step and stepless torque transmission from the electric motor M (drive) to the spindle; for example, for gears, the limiting circumferential speeds are limited by the requirements for noise (acoustic) characteristics, and for belt drives by slipping, etc. ;

3) clamping chucks for rod and artificial workpieces, in which the drop in clamping force is associated with the influence of centrifugal forces of unbalanced elements (mainly clamping cams). Even with the introduction of centrifugal force compensation [2,8], the maximum speed is limited by the strength of the elements of the cartridge and, in particular, its body, which can explode like a bomb;

4) imbalance of the spindle with clamping chuck, which can lead to vibration and destruction of its parts, and in the drilling and milling machines of the fixed cutting tool due to the occurrence of unbalanced loads - forces $F_g = m_{ch} \omega^2 e$, where m_{ch} is the mass of the cartridge and e is the eccentricity of the shift of

2. Evolution of the development of the drive of the main movement of metal-cutting machines

The whole history of the development of machines, from the Stone Age to modern times, is associated with the evolution of its individual mechanisms, components, assemblies, control systems. According to the laws of development of technical systems (TS), the life cycle is described by an S-shaped curve, where in the coordinate system (important characteristic - time), its individual parts develop unevenly, which is influenced by human achievements in science and technology. This also applies to the main movement, which has gone through various stages of use of energy sources and its converters, namely: - biological (human from the hands and feet, with the involvement of animals such as horses); - natural (water wheel, air - windmills); - steam engine; - electric motors; - alternative sources (solar, chemical, biofuels, hydrogen, etc.). And only with the discovery in the 18th century of electric current in all spheres of human life there were significant changes, which were also reflected in metal-cutting, woodworking, stone processing machines and other technological equipment not only in drive systems but also in control systems. control and information. Without electricity, it is now impossible

3. Areas of research of the Kiev school in the field of spindle nodes and MS

Scientists of Donbass Machine-Building Academy (Kramatorsk) for heavy-duty machines, Chernihiv Polytechnic for universal lathes and circular grinders [6], Igor Sikorsky Kyiv Politechnic Institute for lathes, drills, drills including parallel kinematics, and new generation mobile machines without mechanical transmissions [1-3,5,8,9]. Research in Ukraine and abroad has recently focused on the widespread use of M-W, which provides only the main rotational motion, where there are no mechanical transmissions, and torque is transmitted by electromagnetic field between the stator mounted in the spindle head housing and the rotor, which is made in the form of a spindle with a clamping mechanism, which may have a mechanized clamp drive, and in its absence - a clamping chuck with a manual clamp, mainly collet. Some M-S designs use air and electromagnetic bearings. The main advantages of such spindles on magnetic bearings: lack of mechanical contacts and, as a consequence, wear; the possibility of using higher (compared to traditional designs) speeds; minimal vibration, no friction and reduced heat loss; the ability to change the stiffness and damping characteristics of the system; ability to work in vacuum and harmful environments; ecological purity. The rapid development of technology encourages the development of new and more advanced types of M-S [9,10]. Problems of structural synthesis of electromechanical objects and systems belong to the category of the most complex search problems, which are set in the absence of clear input information. Traditionally, solving this type of problem involves the use of heuristic search methods or the professional intuition of the researcher. The Igor Sikorsky Kyiv Politechnic Institute at the Department of Machine and Machine Design (Mechanical and Mechanical Engineering Institute) in cooperation with the Department of Electromechanics (Faculty of Electroautomatics) drilling and milling machines with mechanisms of parallel structure, built on the modular principle. The genetic approach is based on the principles developed at the

4. Using the theory of evolution to build models of M-S

The evolution of EM systems is accompanied by an intensively growing variety of functional classes and structural varieties, the complexity of their structural organization,

the mass of the cartridge and the moments $M_g = F_g e = m_{ch} \omega^2 e^2$;

5) the clamp drive, which creates the initial force of the clamp when, and on the occasion of automatic control, compensates for the loss, for example by increasing the pressure when using the hydraulic drive; in the presence of unbalanced elements in the clamp drive, for example, with a geometric circuit, centrifugal forces acting on unbalanced elements (levers, rollers, balls) can reduce or increase energy loss on the clamp-clamp, disrupt reliable operation of the drive, and therefore the entire clamp mechanism [4].

to imagine human life on earth and beyond. Therefore, the future of the new generation of machines can not be imagined without the use of electromagnetic energy. The evolution of spindle assemblies can be traced using spindle supports, which significantly affect the performance and, in particular, to ensure speed [1]. Modern designs of spindle assemblies use rolling bearings, hydrostatic, hydrodynamic, gas-static (aerostatic), gas-dynamic (aerodynamic), magnetic bearings and their combinations (hybrids), such as gas-magnetic (gas-bearing bearings with magnetic suspension) [5,6]. The increase in the speed of spindle assemblies using the energy of electromagnetic forces was facilitated by the consistent reduction of the kinematic circuit from the power source to the workpiece or tool: first, a group electric drive for several machines; then common to one machine with stepped gears; then individual with stepped gearbox; finally individual coaxial through couplings, and then high-speed pneumatic spindles and electric spindles. The latter were called "Motor Spindle" (MS).

Department of Electromechanics to solve problems of directed structural synthesis of electromechanical systems (EM systems) with the completeness of their potential solutions due to the open periodic table of primary sources of electromagnetic fields [7]. This opens the possibility of implementing not only the directed synthesis and genetic prediction of electromechanical structures of arbitrary level of complexity for a given function of the target. From the point of view of genetic approach, M-S systems are complex combined genetically determined systems that can combine representatives of several types of electromechanical EM systems with components and mechanical components of other genetic nature (sensors, hydraulic systems, different types of bearings, etc.) [6,9,10]. The system-morphological approach was based on the concept developed at the Department of Machine and Machine Design, which considers the complex process of optimal design of the technical system in the form of sequential solution of multivariate, multilevel, multicyclic, multicriteria and multiextreme problems of synthesis, analysis and measurement. modular principle and modern information technology [2]. Today there is an urgent need to create M-S that can provide direct rotation of the spindle and feed movement, as well as implement complex helical spindle movement without the use of transmission mechanisms, as this allows to expand the functionality of spindle assemblies and reduce machine dimensions. Such EM-systems include, first of all, representatives of hybrid EM-objects of the twin type [8,9], however, the results of information retrieval indicate that in the studied class of combined EM-systems of the type "M-W", to date, there are no M-W, which have such properties. Thus, the task arose with the use of structural prediction technology to synthesize new structures M-W, able to directly implement the rotational movement of the spindle and the feed movement, as well as to implement complex helical movement of the spindle without the use of transmitted mechanisms.

integration with components of other systems (mechanical, electronic, hydraulic, biological, etc.), progressive volumes of accompanying information. The organization of exploratory

research, selection and justification of competitive design solutions is associated with significant costs of material and time resources, which requires the development of new methodological approaches that can reproduce complete, reliable and systematic information on structural capacity within arbitrary classes of EM systems, regardless of level their complexity and functional affiliation [7]. Solving the problems caused by the growth of M-W diversity belongs to the latest current scientific field of research in modern mechanics and electromechanics, which is generalized to the concept of structural and systems research with models of microevolution and macroevolution [6,7,9,10]. The tasks of microevolution are the search, creation and improvement of specific EM systems (creation of new structural types of EM), and macroevolution - the search for

patterns of development over species classes of systems, development of generalized genetic models, creation of information databases, construction of general EM systems [7]. Hybrid electromechanical structures are characterized by mixed genetic information, so their functional properties are determined by the corresponding functions inherent in the generative species [12]. Hybrid species include functional classes of multistage electric machines with complex spatial motion of the moving part, as well as other classes of complex EM systems, which are characterized by mixed genetic information. Systems of the type "M-W" are complex combined electromechanical structures [11,12] which include mechanical and electromagnetic parts.

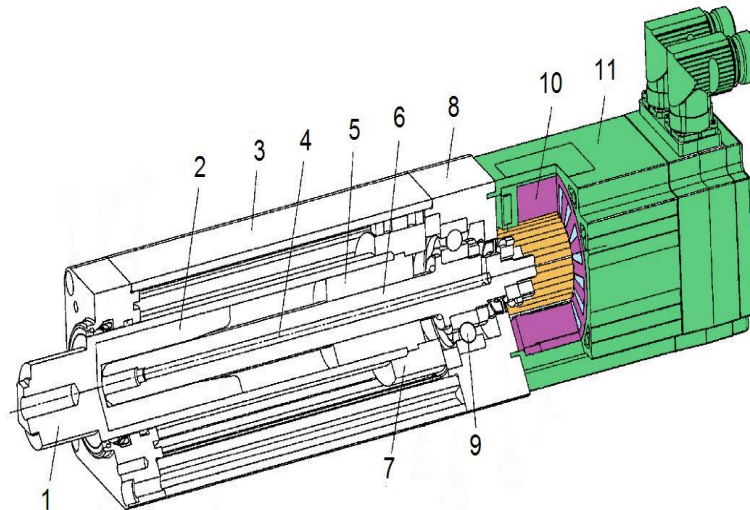


Fig. 2. Motor-spindle in section: 1 - spindle; 2-support cylinder; 3 - the body of the mechanical part of the M-W; 4 - department for oil supply; 5 - running spindle; 6 - spindle nut; 7-centering guide; 8 - casing; 9 - bearing; 10 - motor stator; 11 - engine housing

The results of genetic analysis of known species M-S of the studied class were used to organize its identified representatives on the basis of genetic traits, as well as source information for building models of micro- and macroevolution, which, in turn, are used for targeted synthesis of new structures of class M-S. The main stages of this procedure are information-patent search in class M-S and analysis of genetic information on known types of EM, identified by the results of information search, which need to be reviewed and supplemented over time. From the point of view of genesystematics, an arbitrary functional class M-S can be represented as a corresponding set of genetically determined Species and Genus. This is the universality of the methodology of taxonomy. Another fundamental property of genesystematics is its prognostic function, ie, the ability to determine both real-information and implicit species that are not yet involved in the current evolution of the class. The source information for determining the structure and quantitative composition of the main systematic units for the studied class is the area of existence of generating electromagnetic structures and the structure of their genetic codes. The availability of such information allows to determine: -systematic units of the genus rank (according to the affiliation of generating structures to the corresponding geometric classes of genetic classification); -quantitative composition and

structure of systematic units of the rank of the species and their distribution by genus; -the ratio of real-information and implicit species, and their distribution by genus. The rank structure of genesystematics is a generalization of the results of determining the systematic units of the studied class and can be presented in graphical form.

A genetic model of synthesis of combined electromechanical structures M-S with the implementation of reciprocating motion by converting rotational motion into translational motion through the use of "screw-nut" transmission was built (Fig.3). One of the embodiments of the synthesized chromosome S31 (fig.3) is presented in fig.4. When voltage is applied to the stator winding 4, there is a magnetic field that interacts with the two-layer active surface of the rotor 6 and, thus, causes the spindle 7 to rotate with the desired speed n (ω). To ensure the supply of the spindle, the voltage is applied to the motor 1, the speed of which by means of the CNC system is converted through the screw pair 2, 3 to the translational movement of the quill 5, providing the desired supply S.

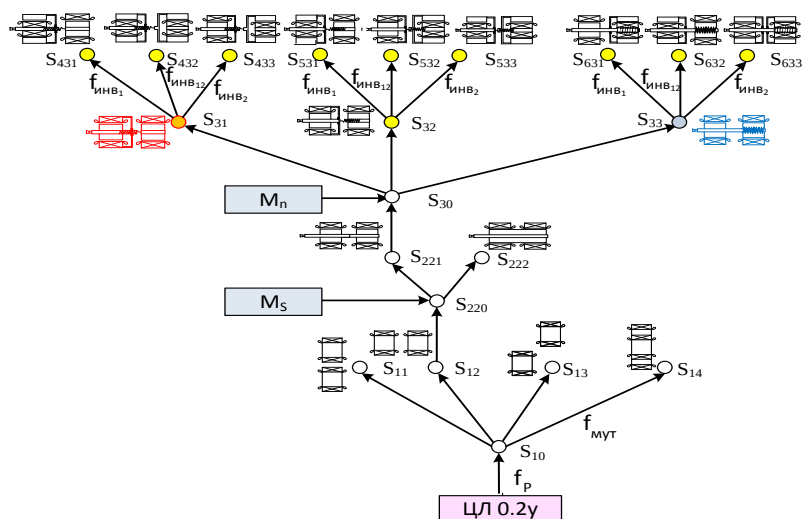


Fig.3. Genetic model of synthesis of M-S hybrid structures with screw-nut system

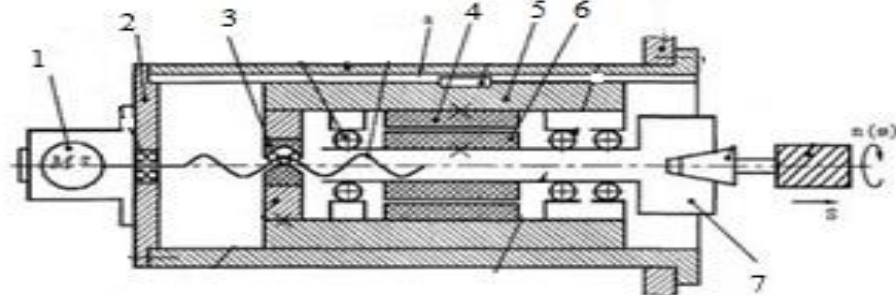


Fig.4. Schematic kinematic scheme of a spindle assembly of flange type

5. Morphological synthesis of non-self acting and self-acting M-S

If genetic synthesis allows to find new structures of M-W and spindle nodes on their basis [7,9], then for the synthesis of schemes and structures it is advisable to use a system-morphological approach [2,3]. In set-theoretic language, the morphological description contains four: $S_m = \{E, R, Str, K\}$, where $E = \{E_i\}$ and - the set of elements and their properties; element-subsystem, inside which the morphological description does not penetrate; $R = \{R_{and}\}$ and - the set of connections; Str - structure (determined by the genetic code); K - composition (arrangement in space). To develop a morphological model, functional (morphological) features are selected, which are divided into three groups in accordance with the modular principle.

For the first module of the drive of rotary main movement signs are selected: 1. Power source. 2. Primary field source. 3. The number of spindle supports. 4. Type of spindle supports. 5. Supports of radial fixing of a spindle. 6. Supports of axial fixing of a spindle. 7. Communication between spindles. 8. The connection of the spindle with the primary source of the field. 9.

Geometric axis of the spindle. 10. Relative location of spindles. 11. Execution of the spindle body.

For the second translational drive module: 12. Power source. 13. Primary field source. 14. Type of motion transducer. 15. Location of guides. 16. Execution of guides.

For the third module of the clamping mechanism: 17. Type of the clamping cartridge on the converter of movement and force. 18. Base surface of the clamping chuck for connection to the spindle. 19. Power source in the clamp-expansion drive. 20. Primary source of the field. 21. Type of energy (force) converter. The morphological model can be written with a morphological matrix in a condensed form $Mshv = Msh \wedge Mn \wedge Mz$, where Msh , Mp , Mz - morphological matrices, respectively, the modules of the rotational motion of the spindle, the drive feed -translational motion and the clamp-expansion. Experimental studies of the manufactured prototype of the synthesized self-acting M-W (fig.4,5) showed its efficiency. After improvement of a design on manufacturability and conformity to the international standards on standard sizes and connections to CNC machines of various models such self-acting M-Sh can be recommended for introduction in production.

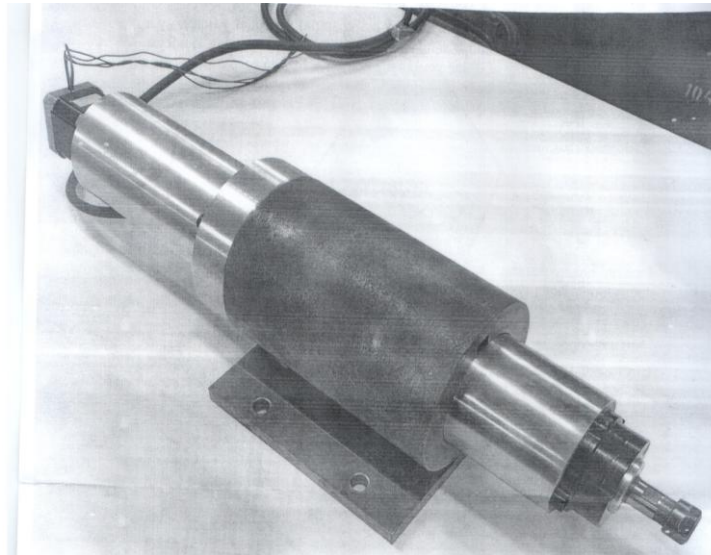


Fig.5. Modular design of self-propelled M-W with "screw-nut" transmission

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Energy analysis of a steam turbine with two cylinders and steam re-heating

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Abstract: This paper presents an energy analysis of middle-power steam turbine with two cylinders (High Pressure Cylinder - HPC and Low Pressure Cylinder - LPC) and steam re-heater after the HPC (and before the LPC). Based on a steam operating parameters from the literature, performed energy analysis show that LPC develops higher power and has higher energy efficiency (81.45%) in comparison to HPC (which energy efficiency equals 80.12%). Re-heater is a heat exchanger (flue gases are used for steam heating) which has low energy loss (824.19 kW) and high energy efficiency (97.76%), what is expected energy performance of such heat exchanger. The entire analyzed turbine develops a power of 127480.60 kW and has energy loss equal to 29848.21 kW with energy efficiency of 81.03%.

KEYWORDS: STEAM TURBINE, TURBINE CYLINDERS, STEAM RE-HEATING, ENERGY ANALYSIS

1. Introduction

Nowadays, steam turbines are mostly used for the electricity production in steam power plants [1]. Such high-power steam turbines usually consist of at least three turbine cylinders (high, middle and low pressure cylinders) connected to the same shaft which drives an electricity generator [2].

As opposite to high-power steam plants, it is also possible to find a lot of steam power plants with low or medium developed power. Steam turbines in such plants usually consist of only one [3, 4] or two [5] turbine cylinders. In such situations, if the steam turbine is composed of two cylinders, between them is usually mounted steam re-heater, which increases steam temperature before expansion in the second cylinder [6].

In this paper is presented an energy analysis of middle-power steam turbine, which consists of two cylinders (High Pressure Cylinder - HPC and Low Pressure Cylinder - LPC) with steam re-heater after HPC. Energy power of each fluid flow stream was investigated. It is presented change in ideal and real developed power of each cylinder and the entire turbine. For the steam re-heater is calculated energy inputs and outputs. For each component of investigated turbine are calculated energy loss and energy efficiency.

2. Description and characteristics of analyzed steam turbine with two cylinders and steam re-heating

Analyzed steam turbine with all of its components is presented in Fig. 1. Steam turbine has two cylinders, High Pressure Cylinder - HPC and Low Pressure Cylinder - LPC. Between turbine cylinders is mounted steam re-heater - heat exchanger which uses flue gases to increase the steam temperature before it enters into LPC.

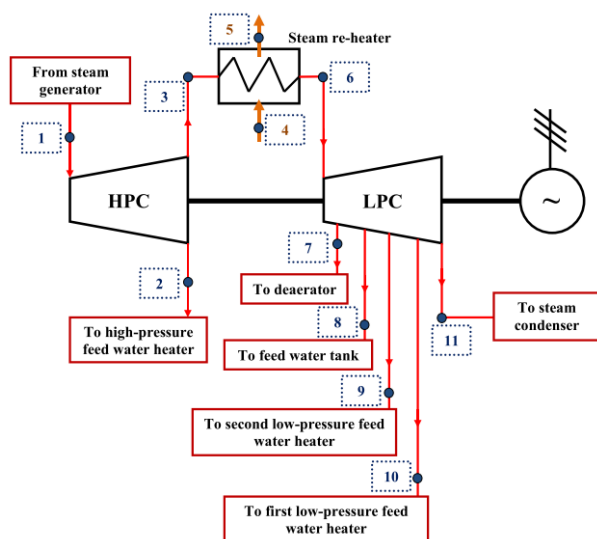


Fig. 1. Scheme and operating points of the analyzed steam turbine with steam re-heating

HPC gets steam directly from steam generator and has one steam extraction, near the cylinder end - those extraction lead steam to high-pressure feed water heater. Remaining steam at the HPC outlet after the expansion was led to steam re-heater. LPC gets steam after re-heater, which increases its temperature. LPC has four steam extractions which led steam to deaerator, feed water tank and to two low-pressure feed water heaters. After expansion, steam was led from the LPC directly to steam condenser. Both steam turbine cylinders are connected with one shaft and the produced power is delivered by the same shaft to an electricity generator.

Based on steam operating parameters at each observed point from Fig. 1 (which are presented in Table 1), it is drawn observed steam expansion process in h-s diagram by using NIST-REFPROP 9.0 software [7] and presented in Fig. 2. The operating points of the real steam expansion process in Fig. 2 are drawn by using the same marking as in Fig. 1, while the operating points of ideal (isentropic) steam expansion process in Fig. 2 are marked with extension - is. Ideal (isentropic) steam expansion assumes always the same steam specific entropy. The same markings are used in equations for the turbine energy analysis. From Fig. 2 can be seen that all observed turbine process is in the field of superheated steam except at the end of expansion in LPC (operating points from 10 to 11) when the process falls in the steam saturated area. Steam re-heat process is characterized by an increase in superheated steam temperature and with a pressure drop during heat exchange.

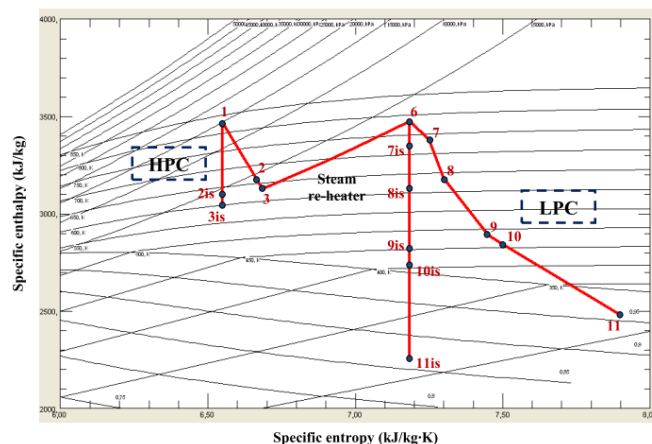


Fig. 2. Operating process of the analyzed steam turbine in h-s diagram (for each turbine cylinder are presented ideal (isentropic - index is) and real (polytropic) steam expansions)

3. Energy analysis

Energy analysis of any control volume or a system is defined by the first law of thermodynamics [8] which is based on the energy conservation [9]. Energy analysis does not take into account the parameters of the ambient (temperature and pressure) in which control volume or a system operates [10].

3.1. Overall equations for the energy analysis

For the analyzed control volume (steam turbine with all of its components) or a system are valid the same overall energy analysis equations. Mass and energy balance equations for a control volume or a system in steady state can be found in [11, 12]:

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \quad (1)$$

$$\dot{Q}_{in} + P_{in} + \sum \dot{m}_{in} \cdot \left(h + \frac{c^2}{2} + g \cdot z \right)_{in} = \dot{Q}_{out} + P_{out} + \sum \dot{m}_{out} \cdot \left(h + \frac{c^2}{2} + g \cdot z \right)_{out} \quad (2)$$

Energy power of a flow for any fluid stream is [13]:

$$\dot{E}_{en} = \dot{m} \cdot h \quad (3)$$

A general energy efficiency equation of any system or control volume can be defined according to [14, 15] as:

$$\eta_{en} = \frac{\text{Energy output}}{\text{Energy input}} \quad (4)$$

3.2. Equations for the energy analysis of investigated turbine

Energy analysis of the investigated steam turbine and all of its components is based on turbine operating points presented in Fig. 1 and Fig. 2. For the High Pressure Cylinder (HPC) energy analysis equations are (according to [16]):

HPC real (polytropic) developed power:

$$P_{HPC,RE} = \dot{m}_1 \cdot (h_1 - h_2) + (\dot{m}_1 - \dot{m}_2) \cdot (h_2 - h_3) \quad (5)$$

HPC ideal (isentropic) power:

$$P_{HPC,IS} = \dot{m}_1 \cdot (h_1 - h_{2is}) + (\dot{m}_1 - \dot{m}_2) \cdot (h_{2is} - h_{3is}) \quad (6)$$

HPC energy loss:

$$\dot{E}_{en,HPC,loss} = P_{HPC,IS} - P_{HPC,RE} \quad (7)$$

HPC energy efficiency:

$$\eta_{en,HPC} = \frac{P_{HPC,RE}}{P_{HPC,IS}} \quad (8)$$

Energy analysis equations for the Low Pressure Cylinder (LPC) are (according to [17]):

LPC real (polytropic) developed power:

$$P_{LPC,RE} = \dot{m}_6 \cdot (h_6 - h_7) + (\dot{m}_6 - \dot{m}_7) \cdot (h_7 - h_8) + (\dot{m}_6 - \dot{m}_7 - \dot{m}_8) \cdot (h_8 - h_9) + (\dot{m}_6 - \dot{m}_7 - \dot{m}_8 - \dot{m}_9) \cdot (h_9 - h_{10}) + (\dot{m}_6 - \dot{m}_7 - \dot{m}_8 - \dot{m}_9 - \dot{m}_{10}) \cdot (h_{10} - h_{11}) \quad (9)$$

LPC ideal (isentropic) power:

$$P_{LPC,IS} = \dot{m}_6 \cdot (h_6 - h_{7is}) + (\dot{m}_6 - \dot{m}_7) \cdot (h_{7is} - h_{8is}) + (\dot{m}_6 - \dot{m}_7 - \dot{m}_8) \cdot (h_{8is} - h_{9is}) + (\dot{m}_6 - \dot{m}_7 - \dot{m}_8 - \dot{m}_9) \cdot (h_{9is} - h_{10is}) + (\dot{m}_6 - \dot{m}_7 - \dot{m}_8 - \dot{m}_9 - \dot{m}_{10}) \cdot (h_{10is} - h_{11is}) \quad (10)$$

LPC energy loss:

$$\dot{E}_{en,LPC,loss} = P_{LPC,IS} - P_{LPC,RE} \quad (11)$$

LPC energy efficiency:

$$\eta_{en,LPC} = \frac{P_{LPC,RE}}{P_{LPC,IS}} \quad (12)$$

Energy analysis equations for the entire steam turbine:

Turbine real (polytropic) developed power:

$$P_{turbine,RE} = P_{HPC,RE} + P_{LPC,RE} \quad (13)$$

Turbine ideal (isentropic) power:

$$P_{turbine,IS} = P_{HPC,IS} + P_{LPC,IS} \quad (14)$$

Turbine energy loss:

$$\dot{E}_{en,turbine,loss} = P_{turbine,IS} - P_{turbine,RE} \quad (15)$$

Turbine energy efficiency:

$$\eta_{en,turbine} = \frac{P_{turbine,RE}}{P_{turbine,IS}} \quad (16)$$

Equations for the energy analysis of steam re-heater [18]:

Steam re-heater energy input:

$$\dot{E}_{en,re-heater,in} = \dot{m}_4 \cdot h_4 - \dot{m}_5 \cdot h_5 = \dot{m}_4 \cdot (h_4 - h_5) \quad (17)$$

Steam re-heater energy output:

$$\dot{E}_{en,re-heater,out} = \dot{m}_6 \cdot h_6 - \dot{m}_3 \cdot h_3 = \dot{m}_6 \cdot (h_6 - h_3) \quad (18)$$

Steam re-heater energy loss:

$$\dot{E}_{en,re-heater,loss} = \dot{E}_{en,re-heater,in} - \dot{E}_{en,re-heater,out} \quad (19)$$

Steam re-heater energy efficiency:

$$\eta_{en,re-heater} = \frac{\dot{E}_{en,re-heater,out}}{\dot{E}_{en,re-heater,in}} \quad (20)$$

4. Operating parameters of the analyzed steam turbine

Operating parameters of the investigated steam turbine (Fig. 1) were found in [19] and modified in order to perform complete energy analysis. Modified steam and flue gases operating parameters (temperatures, pressures and mass flow rates from each operating point - Fig. 1) are presented in Table 1. From known pressures and temperatures are calculated additional operating parameters of steam in each operating point required for the energy analysis – specific enthalpies, specific entropies and specific volumes by using NIST-REFPROP 9.0 software [7].

Specific enthalpies of flue gases in each operating point are calculated by using the following equation:

$$h_{FG} = c_{p,FG} \cdot T_{FG} \quad (21)$$

where the specific heat capacity at constant pressure of flue gasses is a function of current flue gas temperature and is calculated as [19]:

$$c_{p,FG} = 0.9375 + \frac{0.03074}{10^2} \cdot T_{FG} + \frac{0.003116}{10^5} \cdot T_{FG}^2 - \frac{0.03902}{10^9} \cdot T_{FG}^3 \quad (22)$$

In the equation (22) flue gases temperature should be placed in (K) to obtain specific heat capacity at constant pressure c_p in (kJ/kg·K).

Table 1. Steam and flue gases operating parameters of the analyzed turbine (modified from [19])

O. P.*	Fluid	Temperature (K)	Pressure (kPa)	Mass flow rate (kg/s)
1	Steam	829.60	14896.00	119.25
2	Steam	643.15	3890.00	15.51
3	Steam	635.93	3667.00	103.74
4	Flue gases	1139.23	112.84	177.88
5	Flue gases	1002.48	110.74	177.88
6	Steam	785.32	3580.00	103.74
7	Steam	737.41	2353.00	6.97
8	Steam	635.99	1100.00	6.86
9	Steam	484.66	250.00	7.12
10	Steam	459.62	180.00	4.87
11	Steam	316.09	8.625	77.92

* O. P. = Operating Point (according to Fig. 1 and Fig. 2).

5. The results and discussion

Energy power of each fluid flow stream from the analyzed steam turbine is calculated by using equation (3) and presented in Fig. 3 for each observed turbine operating point. The highest energy power has steam at the HPC inlet (operating point 1) which is equal

to 413666.33 kW. The flue gases are the heating medium for steam which exits from the HPC - therefore, energy power of flue gases decreases from operating point 4 to operating point 5, while steam energy power increases from the HPC outlet to the LPC inlet (from operating point 3 to operating point 6, according to Fig. 1). From Fig. 3 should also be noted that energy power of steam flows extracted from both turbine cylinders (operating points 2, 7, 8, 9 and 10) is much lower when compared to energy power of steam flows at each cylinder inlet and outlet (operating points 1, 3, 6 and 11). Energy power of steam flows extracted from both turbine cylinders decreases developed power of each cylinder and the entire turbine what can be considered as turbine (or cylinder) lost power [20].

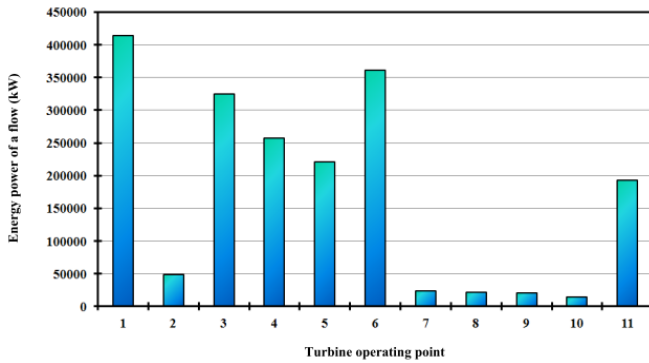


Fig. 3. Energy power of each fluid flow stream from the analyzed steam turbine and its steam re-heater

Real (polytropic) developed power of the entire analyzed steam turbine equals to 127480.60 kW (39966.42 kW for the HPC and 87514.18 kW for the LPC), Fig. 4. Ideal (isentropic) power of the entire steam turbine, as well as of each turbine cylinder, is always higher than the real (polytropic) one, because the ideal expansion process assumes always the same steam specific entropy, Fig. 2. Therefore, the ideal (isentropic) power of the entire steam turbine equals to 157328.81 kW (49885.02 kW for the HPC and 107443.79 kW for the LPC). Energy loss of the entire turbine and each turbine cylinder is the difference between the ideal (isentropic) and real (polytropic) turbine or cylinder power. For the entire turbine energy loss equals to 29848.21 kW (9918.60 kW for the HPC and 19929.61 kW for the LPC), Fig. 4.

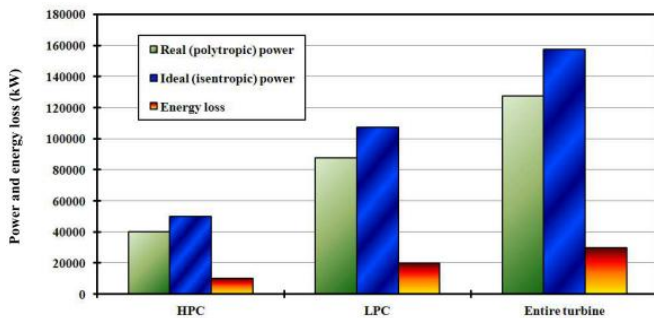


Fig. 4. Energy loss and developed power (real and ideal) for each turbine cylinder and the entire steam turbine

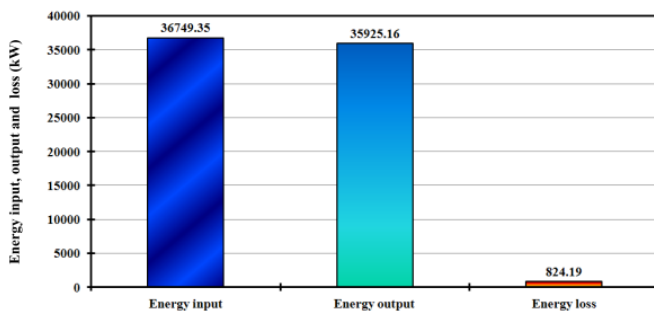


Fig. 5. Energy input, output and loss of steam re-heater from the analyzed steam turbine system

From the energy point of view, heat exchangers are usually well balanced devices with low energy losses and high energy efficiencies [21-23], what is also valid for steam re-heater which is a constituent part of the observed system. Steam re-heater from the analyzed turbine system has an energy loss equal to 824.19 kW, Fig. 5.

Energy input in steam re-heater represents heat amount transferred from the flue gases to steam and equals 36749.35 kW, while the steam re-heater energy output is heat amount actually transferred from flue gases to steam which is lower in comparison to energy input for losses during heat transfer.

Energy efficiencies of the analyzed steam turbine and all of its components are presented in Fig. 6. Regardless of worse operating conditions and entrance into the saturated area in the last few stages [24], LPC has higher energy efficiency in comparison to HPC (81.45% for LPC and 80.12% for HPC). The energy efficiency of the entire steam turbine (81.03%) is between energy efficiencies of HPC and LPC. As mentioned before, a heat exchanger (steam re-heater) has low energy loss and simultaneously high energy efficiency which is equal to 97.76%, Fig. 6.

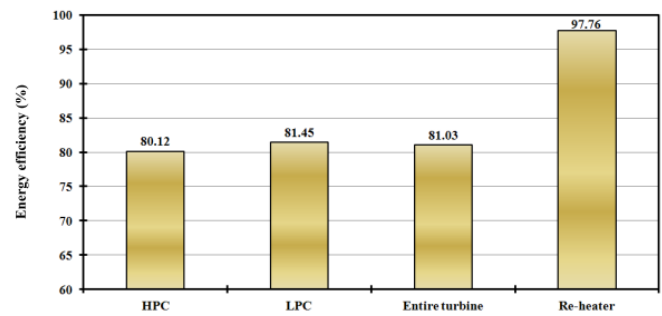


Fig. 6. Energy efficiencies for all observed components of the analyzed steam turbine system

6. Conclusions

In this paper is presented an energy analysis of steam turbine with two cylinders and steam re-heater between cylinders. For all of the observed steam turbine components are calculated required operating parameters, energy losses and energy efficiencies. The most important conclusions of the presented analysis are:

- Energy power of fluid flows throughout turbine is much higher at turbine cylinders inlet and outlet in comparison to steam extractions.
- LPC of the analyzed turbine develops higher power and has a higher energy loss in comparison to HPC. This fact leads to higher energy efficiency of LPC (81.45%) in comparison to HPC (80.12%).
- Steam re-heater, as many other heat exchangers, has low energy loss (824.19 kW) and proportionally high energy efficiency (97.76%).
- According to presented operating parameters, the entire analyzed turbine produced real power equal to 127480.60 kW, has energy loss equal to 29848.21 kW and its energy efficiency is 81.03%.

7. Nomenclature

Abbreviations:

HPC High Pressure Cylinder
LPC Low Pressure Cylinder

Latin symbols:

c velocity, m/s
 c_p specific heat capacity at constant pressure, kJ/kg·K
 $\dot{E}$ energy power of a flow, kW
 g acceleration of gravity, m/s²
 h specific enthalpy, kJ/kg
 $\dot{m}$ mass flow rate, kg/s

T temperature, K
 v specific volume (m³/kg)
 z elevation, m

Greek symbols:

η efficiency, %

Subscripts:

en energy
FG flue gases
in input (inlet)

p	pressure, kPa	IS	isentropic (ideal) steam expansion
P	power, kW	out	output (outlet)
$\dot{Q}$	heat amount, kW	RE	real (polytropic) steam expansion
s	specific entropy, kJ/kg·K		

8. Acknowledgment

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Quality assessment of heterogeneous welding joints made by gmaw method

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Abstract: At present, various types of steel grades are used in the production of welded structures and assemblies, resp. combinations of ferrous and non-ferrous metals. In these mutual combinations, it is necessary to know the specifics of weldability of both materials, to choose a suitable welding technology and a suitable filler material. In the experimental part, the quality of heterogeneous welded joints was verified by the GMAW method. A protective gas atmosphere of 82% Ar + 18% CO₂ was used for welding (M21 - ISO 14175: 2008). The possibilities of welding and mutual combinations of austenitic stainless steel with structural non-alloy steel, structural alloyed high-strength steel with structural non-alloy steel were assessed. The quality of welds was evaluated using non-destructive and destructive tests in terms of standards: visual test STN EN ISO 17637, capillary penetration test STN EN ISO 22476-12, internal errors were evaluated using radiation tests STN EN ISO 17636-1. The destructive tests used the tensile test STN EN ISO 6892-1, the weld fracture test STN EN ISO 5173 and the Vickers hardness test STN EN ISO 6507-1, the bending impact test STN EN ISO 9016 and the metallographic analysis according to STN EN ISO 17639.

KEYWORDS: GMAW METHOD, NON - DESTRUCTIVE TESTING, MECHANICAL PROPERTIES, QUALITY OF JOINTS

1. Introduction

GMAW (MIG / MAG) stands for Gas Metal Arc Welding, which in turn means arc welding with a melting electrode in a protective atmosphere. It is a welding process in which the heat of an electric arc, which burns between the additive and the base material, creates a mutual connection of the materials. The principle of operation is that the current is supplied to the electrode by means of a contact nozzle, i.e. a tip in the torch, which is connected to the positive pole of the current source. The electrode in the form of a wire, which is wound on a coil, is moved by a certain displacement to the place of the weld by a constant speed in a mechanized way by means of pulleys[1]. Subsequently, the electrode melts at the point of arc and the metal from the filler material is transferred to the weld pool. The weld is brought about by a protective atmosphere that protects the weld pool from the adverse effects of the surrounding atmosphere. The advantages of this method lie in high productivity compared to other welding methods. This method is suitable for automation and robotization of welding work and its scheme is shown in Fig.1 [2-4].

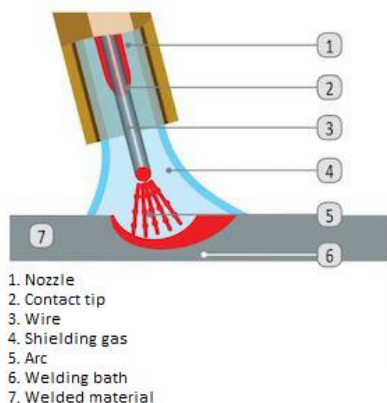


Fig. 1. Scheme of GMAW (MIG / MAG) welding technology

MIG / MAG technology is commonly used to join steels of different grades. However, during welding, the characteristic properties of welding must be taken into account, in particular the large depth of melting of the welded materials. When applying this technology, there is a large mixing of materials in the weld metal. As a result, an undesirable chemical composition of the weld metal may occur. For this reason, GMAW (MIG / MAG) welding uses variants that reduce the depth of the weld. For example, short arc welding or pulse welding is used [5-7].

The subsequent welding procedure must be chosen so that the arc does not directly melt the weld surface, so that it is always oriented correctly to the prefabricated weld bead. It is also convenient to use filler materials that have a lower melting point

than the bonded base materials. These conditions can be provided in particular with different combinations of metallic materials which are mutually soluble or are capable of forming solid solutions in a relatively wide range of mutual concentrations, e.g. in welding Cu and Ni, Cu with single-phase Cu alloys, Al with Al single-phase alloys and the like [8-13].

The additive material is selected on the basis of a common chemical composition than the base material, which has a lower melting point. When welding metals with low mutual solubility by GMAW technology (MIG / MAG), e.g. steels with Cu or Cu alloys, the best solution is to use the so-called metal interlayers which are deposited on one or both welded surfaces. Such formed metal intermediate layers must be of sufficient thickness in order to prevent direct melting of the individual base materials. In Cu welding, such interlayers with a higher Ni or nickel content of high-alloy nickel or copper alloys are often used. By using such interlayers, various other metallurgical problems are often solved, such as e.g. problem with Cu leakage into steel.[14-16]

The primary elements in the protective atmospheres used in GMAW (MIG / MAG) technology are Ar and CO₂. Other secondary elements in multicomponent argon-based protective atmospheres are elements such as He and O₂. Technical argon is produced from air. Argon is divided on the basis of its purity, namely argon 4.6 (Ar 99.996%), argon 4.8 (Ar99.998%) or argon 5.0 (Ar 99.999%). However, in MIG / MAG welding, pure argon is rarely used. Nevertheless, it is a component of many mixed gases used in GMAW (MIG / MAG) welding in a wide range [17]. Carbon dioxide is most often used in GMAW (MIG / MAG) welding. It is used either alone as a shielding gas or as one of the main components of numerous mixed gases formed mainly in combination with argon. Carbon dioxide as a one-component shielding gas can only be used for short-circuit MAG welding of non-alloy and low-alloy steels. However, its advantage is the low price [18-19].

As additional materials in GMAW technology (MIG / MAG) are used solid wire electrodes or so-called tubular electrodes which have a similar chemical composition to the base material have suitable welding properties. Both types of electrodes are supplied wound on steel or plastic coils and are packed in suitable protective packaging that prevents deterioration against moisture or improper handling [20].

The aim of the contribution is to evaluate the quality of welded joints of various qualities on selected basic materials, additional materials and shielding gases. The quality of individual welds will be evaluated using non-destructive and destructive tests.

2. Materials and methods

For the purposes of the experiments, 3 combinations of materials were chosen. The experiments were performed in a combination of structural steel, austenitic stainless steel and nickel alloy. The chemical composition of the individual materials in the following subchapter come directly from the

material sheets. The individual materials used for the experiment are in Table 3 and the combinations of materials are shown in Table 3. 4.

Table 1.Used materials

Materials used in experiment	
A	X2CrNiMo 17-12-2 (1.4404) -austenitic stainless steel, EN 10028 - 7
B	S355J2W- structural non-alloy steel, EN 10025-1
C	NiMo16Cr15W (2.4819) - nickel alloy, DIN 17744 09/2002
D	S235JR + N - structural non-alloy steel, EN 10025 - 2
E	S690QL1 - structural alloy steel, EN 10025 - 2
F	S355J2 + N - structural non-alloy steel, EN 10025 - 2

Table 2.Combinations of individual materials during welding

Number	Combination of used materials
1.	A - B
2.	C - D
3.	E - F

Table 3.Chemical composition of X2CrNiMo 17-12-2, EN 10028 - 7 (% wt)

C	Si	Mn	Ni	Cr	Mo	N	S	P
0.024	0.45	1.28	10.04	16.63	2.02	0.032	0.004	0.036

Table 4.Mechanical properties of material X2CrNiMo 17-12-2, EN 10028 - 7

	Yield strength 0.2%	Limit of strength	A
Measured values	357 MPa	582 MPa	55%

Table 5.Chemical composition of material S355J2W, EN 10025 - 1 (% wt)

C	Si	Mn	P	S	Al	Cu	Cr	Ni
0.073	0.4	1	0.009	0.009	0.031	0.293	0.51	0.17

Table 6.Mechanical properties of material S355J2W, EN 10025 - 1

	Yield strength 0.2%	Limit of strength	A
Measured values	401 MPa	508 MPa	29%

Table 7.Chemical composition of NiMo16Cr15W, DIN 17744 09/2002 (% wt)

C	Si	Mn	Cr	Mo	S	P	Fe	Cu
0.002	0.03	0.40	16.18	15.44	0.002	0.04	5.52	0.05

Table 8.Mechanical properties of NiMo16Cr15W material, DIN 17744 09/2002

	Yield strength 0.2%	Limit of strength	A
Measured values	360 MPa	741 MPa	68%

Table 9.Chemical composition of material S235JR + N, EN 10025 - 2 (% wt)

C	Si	Mn	Ni	Cr	Mo	S	P	Cu
0.14	0.19	0.64	0.01	0.03	0.005	0.004	0.02	0.02

Table 10.Mechanical properties of material S235JR + N, EN 10025 - 2

	Yield strength 0.2%	Limit of strength	A
Measured values	337 MPa	452 MPa	33%

Table 11.Chemical composition of material S355J2 + N, EN 10025 - 2 (% wt)

C	Si	Mn	Ni	Cr	Mo	S	P	Cu
0.17	0.2	1.53	0.01	0.02	0.001	0.008	0.009	0.01

Table 12.Mechanical properties of material S355J2 + N, EN 10025 - 2 (% wt)

	Yield strength 0.2%	Limit of strength	A
Measured values	382 MPa	518 MPa	28%

Table 13.Chemical composition of material S690QL1, EN 10025 - 2 (% wt)

C	Si	Mn	Ni	Cr	Mo	Al	P	Cu
0.159	0.3	0.99	0.19	0.6	0.192	0.04	0.011	0.0013

Table 14.Mechanical properties of material S690QL1, EN 10025 - 2

	Yield strength 0.2%	Limit of strength	A
Measured values	690 MPa	770 MPa	14%

Additive material and shielding gas used for the combination of materials (1), X2CrNiMo 17-12-2 EN 10028 and S355J2W EN 10025

For the given case of welding austenitic stainless steel X2CrNiMo 17-12-2 EN 10028 and structural steel S355J2W EN 10025, an additional material with the designation E309LT0 - 1 was chosen.(C1) on the basis of standard EN13479 with the trade name Shield - Bright 309L X - tra with a diameter of 1.2 mm according to standard EN ISO 17633 - A from ESAB. It is an additional material with a rutile filling intended primarily for welding steels with a chromium content of 22-25% or 10-14% nickel. It is also suitable for welding difficult-to-weld ferritic-martensitic stainless steels and for forming undercoat layers during welding of clad steels. The chemical composition of the additive material is shown in Table 17 and its mechanical properties are shown in Table 18. A mixture of gases M21 ISO

14 175 18% CO₂ + 82% Ar was chosen as the protective atmosphere.

Table 15.Chemical composition of additive E309LT0 - 1 (C1) EN ISO 17633 - A

	C	Si	Mn	P	S	Cr	Ni	Fe
Volume%	0.032	0.66	1.46	0.021	0.004	24.5	12.8	residue

Table 16.Mechanical properties of additive material E309LT0 - 1 (C1) EN ISO 17633 - A

	Yeld strength 0.2%	Limit of strength	A
Measured values	410 MPa	546 MPa	38%

Additional material and shielding gas used for the combination of materials (2), NiMo16Cr15W, DIN 17744 09/2002 - 7 and S235JR + N EN 10025 - 2

For the given case of welding of nickel alloy NiMo16Cr15W, DIN 17744 09/2002 and structural steel S235JR + N EN 10025 - 2, THERMANIT NIMO C24 was chosen as additional material on the basis of standard STN EN ISO 18274 with a diameter of 1.2 mm. It is a solid wire. This filler material is suitable due to the high nickel content for welding nickel-based alloys but also its combinations with structural steel. It has excellent resistance to corrosion and oxidizing environments. The chemical composition of the additive material is shown in Table 19 and its mechanical properties are shown in Table 20. Inoxline HE30H2C was chosen as the shielding gas on the basis of the STN EN ISO 14175 standard. This shielding gas is composed of 68.8% argon, 30% helium, 2% hydrogen and 0.12% carbon dioxide.

Table 17.Chemical composition of the additive marked THERMANIT NIMO C24 EN ISO 18274

	C	Si	Mn	P	Fe	Cr	Mo	Ni
Volume%	0.01	0.1	0.2	0.005	0.3	23	16.1	residue

Table 18.Mechanical properties of the additional material with the designation THERMANIT NIMO C24 EN ISO 18274

	Yeld strength 0.2%	Limit of strength	A
Measured values	420 MPa	700 MPa	40%

Additional material and shielding gas used for the combination of materials (3), S355J2 + N EN 10025 - 2 and S690QL1 EN 10025 - 2

For the given case of welding the combination S355J2 + N EN 10025 - 2 and S690QL1 EN 10025 - 2, an additional material with the designation OK ARISTOROD 55 with a diameter of 1.2 mm was used on the basis of the standard EN ISO 16834 - A. It is a solid non-copper alloy wire. It is used for welding high-strength steels. The chemical composition of the additive material is shown in tab. 21 and its mechanical properties are shown in tab. 22. The M21 Arc 18 gas with an argon content of 82% and a carbon dioxide content of 18% was chosen as the shielding gas on the basis of EN ISO 14175.

Table 19.Chemical composition of the additive marked OK ARISTOROD 55 EN ISO 16834 - A

	C	Si	Mn	P	S	Cr	Ni	Fe
Volume%	0.12	0.71	1.38	0.013	0.005	0.58	0.53	residue

Table 20.Mechanical properties of the additional material marked OK ARISTOROD 55 EN ISO 16834 - A

	Yeld strength 0.2%	Limit of strength	A
Measured values	690 MPa	770 MPa	20%

Designation of evaluated samples

Individual test specimens made of different combinations of materials carry their markings so that the individual specimens cannot be confused throughout the process. The designation of the samples is shown in tab. 23.

Table 24.Identification of individual test specimens

Combination of used materials	Designation of evaluated samples
A-B	ST 5
C-D	CO 011
E-F	RS 29



Fig. 4.Sample of material combination A -B (1)



Fig. 5.Sample of material combination C -D (2)

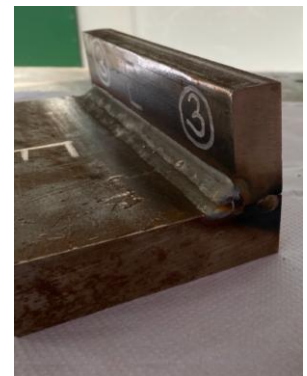


Fig. 6.Sample of material combination E - F (3)

Testing methodology

- Visual examination according to STN EN ISO 17 637
- Capillary (penetration) test according to STN EN ISO 22476 - 12
- Radiation test method according to STN EN ISO 17636 - 1
- Tensile test according to STN EN ISO 6892 - 1
- Test of fracture of welds of metallic materials according to STN EN ISO 5173
- Vickers hardness test according to STN EN ISO 6507 - 1
- Bending impact test according to STN EN ISO 9016
- Metallographic test according to STN EN ISO 17639

3. Results

Visual tests according to STN EN ISO 17 637

Table 25. Visual test report on test specimen marked ST 5

Object	Butt weld	Dimensions of specimen	t=12mm
Identification of specimen	ST5	Surface quality	Mechanical
Material	1.2+8.1 CR ISO 15608	Heat treatment	-
Type of welding	136/PA	Dimensions of weld	-
Done by code	STN EN ISO 6520- 1	Range of testing	100% weld surface 15mm surroundings
Evaluated by	STN EN ISO 5817	Lighting	520 lx

According to Visual test report sample was admissible.

Table 26. Visual test report of the CO 011 test specimen

Object	Filet weld	Dimensions of specimen	T ₁ =30mm T ₂ =6mm
Identification of specimen	CO 011	Surface quality	Mechanical
Material	1.1+43 CR ISO 15608	Heat treatment	-
Type of welding	136/PB	Dimensions of weld	A= 4mm
Done by code	STN EN ISO 17637:2011	Range of testing	100% weld surface 15mm surroundings
Evaluated by	STN EN ISO 5817	Lighting	550 lx

According to Visual test report sample was admissible.

Table 27. Visual test report of the test sample marked RS29

Object	Filet weld	Dimensions of specimen	T ₁ =30mm + 20mm
Identification of specimen	RS 29	Surface quality	Mechanical
Material	S355+S690	Heat treatment	-
Type of welding	135	Dimensions of weld	12FW a=9, penetration 1.5
Done by code	STN EN ISO 17637:2011	Range of testing	100% weld surface 15mm surroundings
Evaluated by	STN EN ISO 5817	Lighting	520 lx

According to Visual test report sample was admissible.

Capillary (penetration) tests according to STN EN ISO 22476 – 12

Table 28. Penetration test report of the test specimen marked ST 5

Test specifications	EN ISO 3452-1	EN 23277 level 1	
Object	Butt weld	Identification number	ST5
Material	1.2+8.1 CR ISO 15608	Drawing	-
State of treatment	-	State of test surface	Clean, brush down
Dimensions of specimen	T=12mm		
Extent of testing	100%	Penetrant system	II Cd
Manufacturer	Hellig	Penetrant	Kontrastor 88
Cleaner	Reiniger 87	Developer	Entwickler 89
Inspection temperature	25°C	Penetration time	15 min
Developing time	15 min	Deviations from test specifications	none

According to capillary tests no defects on sample ST5 were found.

Table 29. Penetration test report of the test sample marked CO 011

Test specifications	EN ISO 3452-1	EN 23277 level 1	
Object	Butt weld	Identification number	CO 011
Material	1.1+43 CR ISO 15608	Drawing	-
State of treatment	-	State of test surface	Clean, brush down
Dimensions of specimen	T ₁ =30mm T ₂ =6mm		
Extent of testing	100%	Penetrant system	II Cd
Manufacturer	Diffu-Therm	Penetrant	BDR Ch.NR.2116
Cleaner	BRE Ch.NR.2219	Developer	BDR Ch.NR.2319
Inspection temperature	25°C	Penetration time	15 min
Developing time	15 min	Deviations from test specifications	none

According to capillary tests no defects on sample CO 011 were found.

Table 30. Penetration test report of test sample RS29

Test specifications	EN ISO 3452-1	EN 23277 level 1	
Object	Butt weld	Identification number	RS29
Material	S355+S690	Drawing	-
State of treatment	-	State of test surface	Clean, brush down
Dimensions of specimen	12FW a=9, penetration 1.5		
Extent of testing	100%	Penetrant system	II Cd

Manufacturer	Diffu-Therm	Penetrant	Kontrastor 88
Cleaner	Reiniger 87	Developer	Entwickler 89
Inspection temperature	25°C	Penetration time	15 min
Developing time	15 min	Deviations from test specifications	none

According to capillary tests no defects on sample RS29 were found.

RT radiation test according to STN EN ISO 17636 – 1

Table 31. Radiation test report using RT test specimen marked ST5

Material	Description	NDT plan
S355J2+N	-	-
Quality level	Welding method	Welding position
Test according to	Test according to	Thickness
EN/ISO 17636	EN ISO 10675	12/12mm
Level class	Category of test	Procedure number
2	B	002-1G
Source of radiation	Focus	SFD
Ir192	3mm	400mm
Settings	Film sensitivity	Foll
100Ci-3,7TBq	AGFA Geavert D5	Pb 0.030mm
Film production number	Developer	Densitometry
EACH 4650022	Automatic NDT-E	MD12
Exposition placement	Negatoskop	Scale
Parametric	Seifert	ISO62W10

According to radiation tests on sample ST5 results were satisfying.

Metallographic tests according to STN EN ISO 17639

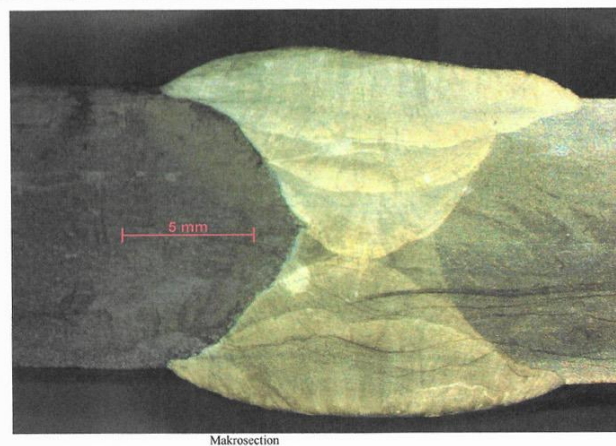


Fig. 20. Metallographic test of the test specimen marked ST5

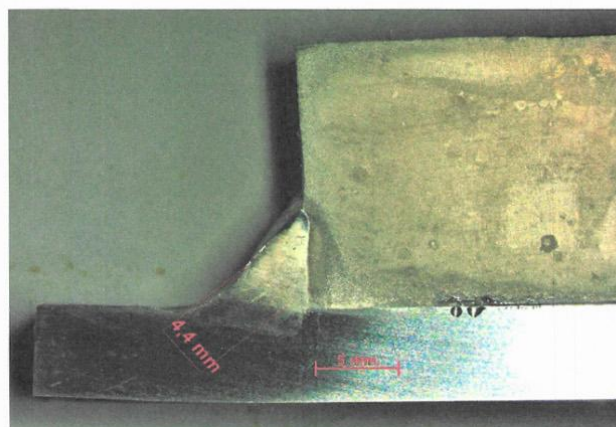


Fig. 21. Metallographic test of the test sample marked CO 011

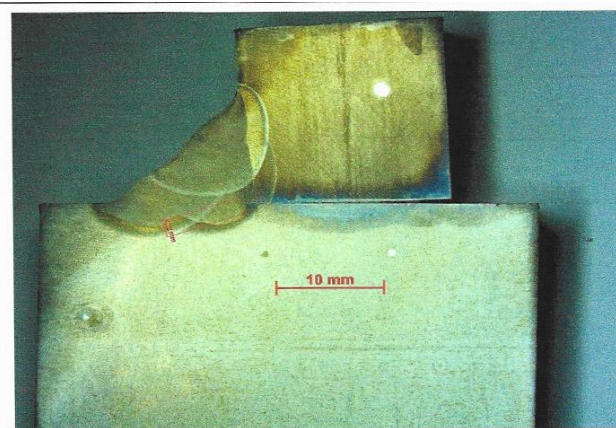


Fig. 22. Metallographic test of the test sample marked RS29

4. Conclusion

The main goal of the article was to point out the evaluation of the quality of welded joints made of different grades of steel using GMAW technology. The consumables used in the individual material combinations were selected from the catalog of welding consumables and were selected with regard to the chemical composition of the base materials. If the difference in the melting temperature of the two base materials is large, the additive material is adapted to the melting temperature of the base material whose melting point is lower. Furthermore, it is important that the additive material has sufficient ductility in order to overcome the thermal

expansion of the individual materials to be joined. Individual shielding gases were selected on the basis of recommendations from Messer Tatragas, spol. Ltd. For the first combination of materials X2CrNiMo 17-12-2 EN 10028 and S355J2W EN 10025, it was chosen as a shielding gas with the designation M21 according to STN EN ISO 14175 because it is suitable for low-alloy and alloyed carbon steels, has excellent mechanical properties and is suitable for different sheet thicknesses. For the second combination of materials NiMo16Cr15W, DIN 17744 09/2002 and S235JR + N EN 10025 - 2 it was chosen as a shielding gas with the designation Inoxline He30H2C according to STN EN ISO 14175 due to the fact that this mixed gas is suitable for welding alloys with a high nickel content, has very good welding metal flow properties and has a stable welding arc. For the last combination of materials S355J2 + N EN 10025 - 2 and S690QL1 EN 10025 - 2, the same shielding gas was chosen as for the first combination of materials.

Non-destructive and destructive tests were subsequently performed for all three combinations of materials, on the basis of which the quality of the welded joint, the suitability of the combination of individual materials, the suitability of the choice of additional material and shielding gas were determined. Based on the results of non-destructive and destructive tests given in the protocols, it can be stated that all combinations of materials with selected additional materials and shielding gases meet the requirements, and the quality of the welded joint is satisfactory.

Acknowledgement:

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Effect of the forging process in a tool implementing alternating deformation on the structure and mechanical properties of aisi-5140h low-alloy structural steel

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Abstract: The article describes the concept of a new forging method of circular cross-section blanks in a forging tool, the design of which makes it possible to develop significant alternating deformations in the deformable metal. The results of comparative studies of the microstructure and mechanical properties of AISI-5140H low-alloy structural steel, formed in a new forging tool that implements alternating deformation and in flat strikers are presented.

Keywords: FORGE, FORGING TOOL, ALTERNATING DEFORMATION, MICROSTRUCTURE, MECHANICAL PROPERTIES.

1. Introduction

One of the advanced methods of metal processing, which allows to significantly reduce the metal consumption coefficient in the manufacture of various metal products, and at the same time will ensure an increase in their quality, is metal forming, including such method as forging. Improving the metal quality when forging ingots and blanks largely depends on the chosen forging technology and

the tool for its implementation. And it has long been proven that one of these technologies is forging technology, which allows additional shear deformations to be realized during deformation [1].

It is possible to achieve significant additional shear deformations during forging in practice for forging workpieces of circular cross-section by using a new forging tool [2] shown in Figure 1.

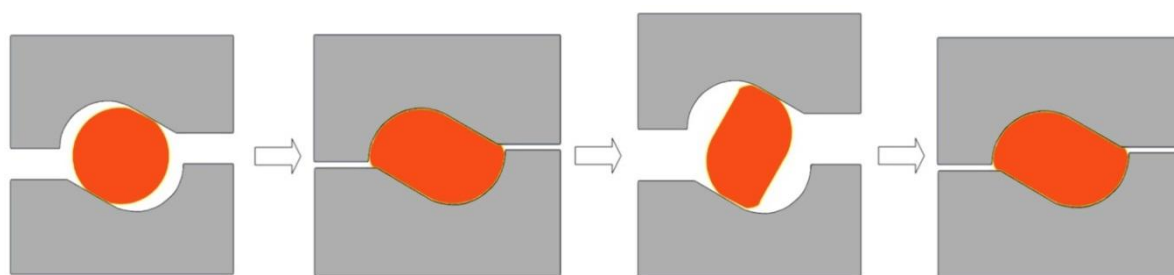


Fig. 1. Forging tool and scheme workpiece deformation

The purpose of this work was to study the influence of the forging process of round cross-section blanks in a forging tool that implements shear deformation in the entire volume of the deformed metal on the microstructure evolution and changes in the mechanical properties of AISI-5140H steel. The choice of AISI-5140H low-alloy structural steel for the experiment is justified by the fact that this steel is widely used in the manufacture of various machine parts and equipment.

2. Experimental part

An experiment on the deformation of AISI-5140H steel billets with dimensions $D \times L = 45 \times 300$ mm in a forging tool of a new design implementing alternating deformation was carried out in laboratory conditions on a hydraulic press with a force of 100 tons. All blanks of AISI-5140H steel were annealed at a temperature of 700°C with an exposure time of 45 minutes to ensure the restoration of the initial structure.

The technology of forging blanks in the new forging tool was as follows: the blanks were preheated to a forging start temperature of 1100°C and were kept at this temperature; then the first billet was

fed into a forging tool of a new design and deformed according to the scheme shown in Figure 1. After the entire billet (along the entire length) was formed according to this scheme, another series of compression of the billet along the entire length was carried out in the same forging tool, but already at first with its edging at 45°, and then at 30°. This made it possible to approximate the shape of the cross-section formed in the new forging tool of the workpiece to a circle having a diameter of 35 mm. The second batch of blanks made of AISI-5140H steel, heated to the temperature of the beginning of forging, was formed according to the current technology - broaching in flat strikers, also up to a diameter of 35 mm. Section reduction in both cases was 1.65.

Metallographic studies of blanks formed according to the proposed and current technologies were carried out on a metallographic microscope DM IRM of Leica (Germany) in accordance with the requirements of GOST 5639-82. Also, non-deformed (annealed) billets made of AISI-5140H steel were subjected to metallographic studies. The results of the microstructure evolution study are shown in Figure 2.

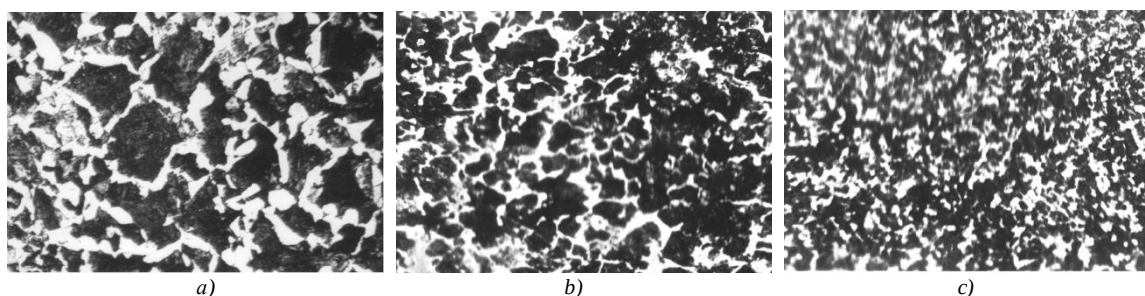


Fig. 2. Microstructure of AISI-5140H steel: a – initial, b – shaped in flat strikers, c – shaped in a new forging tool

Comparison of average grain sizes with reference scales showed that in the initial state, the dimensions correspond to 5 points; after deformation in flat strikers the average grain size lies in the range 6-7 points, and after deformation in a new forging tool - 9 points. So, the grain size of AISI-5140H steel, deformed in a new forging tool, the entire cross-section is 2-3 points higher than when deforming it in flat strikers. At the same time, when deforming workpieces in a new forging tool, there is also a more uniform distribution of equiaxed grains over all sections of the workpiece, compared with flat strikers.

Also, standard tensile samples (type III) were prepared from all experimental blanks (deformed and not deformed) in accordance with GOST 1497-84 "Metals. Tensile testing methods". To conduct tensile tests, the TCB – 101-50 installation was used. During mechanical tests, the following mechanical properties of AISI-5140H steel were determined: tensile strength, yield strength, elongation, contraction. The average values of these mechanical properties obtained after statistical processing of test results are shown in Table 1.

Table 1 – Mechanical properties of AISI-5140H steel

Tool	Property	Average values of properties	
		Initial	After deformation
new forging tool	Tensile strength, MPa	579,7	684,6
	Yield strength, MPa	265,4	344,8
	Elongation,%	10,8	18,7
	Contraction,%	23,7	35,6
flat strikers	Tensile strength, MPa	579,7	654,7
	Yield strength, MPa	265,4	302,4
	Elongation,%	10,8	14,1
	Contraction,%	23,7	28,9

Analysis of mechanical properties shows that the strength characteristics of AISI-5140H steel blanks forged in the proposed forging tool increase more intensively, compared with the strength properties of blanks formed in flat strikers. Thus, when using a new forging tool, the strength characteristics of the workpieces increase on average after one deformation cycle: the tensile strength increased by 18.1%, and the yield strength increased by 23% of its initial values (after annealing). When using flat strikers for forging,

this increase is: the tensile strength increased by 12.9%, and the yield strength increased by 13.9%. The plastic characteristics of the workpieces forged in the proposed tool increase in comparison with their initial values, too, more significantly than when forging with flat strikers. For example, the relative elongation during forging in a new forging tool increases on average by 7.3%, and the relative narrowing by 5%, and when forging in flat strikers, the relative elongation increases by only 3% and the relative narrowing by 2.2%. A more intensive increase in the mechanical properties of blanks forged using the proposed technology in a new forging tool is primarily due to the fact that the compression of blanks in this tool is accompanied by intense shear deformations and, accordingly, more intensive grinding of the initial microstructure, which was proved earlier.

3. Conclusion

The conducted studies have once again proved the advantages of forging workpieces in forging tools, which allow additional shear or alternating deformations to be realized in the entire volume of the deformed metal during the deformation process. Also, the above studies suggest that the introduction of the proposed technology into production will allow to obtain an economic effect, since this technology will allow to obtain forgings and billets of circular cross-section with a given level of mechanical properties with less forging than using flat strikers.

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Optimization of technological parameters of blasting process on metal surface roughness

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Abstract: The main goal of this contribution is study the microgeometry of blasted surfaces. The aim is to design suitable microgeometric characteristics for the description of pretreated surfaces, experimentally verify the influence of blasting agents of various shapes and sizes on the microgeometry of metal surfaces. The following types of evaluation are used to meet this goal: 2D roughness determination and profilograms, 3D surface visualization and surface volume determination. The results of the experimental part will contribute to the optimization of technological parameters of the tearing process.

Keywords: abrasive blasting, surface, microgeometry, blasting means, parameters of roughness

1. Introduction

Blasting is a mechanical type of surface treatment of the base material. Upon impact with the surface of the blasted material, the blasting agent (tool) causes qualitative changes in its surface layers, thus creating the typical surface morphology that characterizes this method of material processing. The character of the blasted surface is given mainly by the shape of the applied grain of the blasting means. The microgeometry of the surface after blasting is also influenced by the hardness of the grain, the particle size distribution of the fraction, the type of material and the weight of the grain of the blasting means. The quantitative effect of blasting is characterized by the blasting regime. Its main parameters are grain flight speed, angle of incidence and substrate quality. [1-2]

The aim of pretreatment of surfaces on which coatings will be subsequently applied is, in addition to achieving the required surface morphology, also its perfect cleaning of scale, corrosion products and other impurities. The type of blasting means and also the different properties of the dirt to be removed have a predominant effect on blast cleaning. When applying the round blasting agent, the dirt is partially pushed into the surface layers, while when blasting with a sharp-edged blasting mean, secondary contamination occurs through the graining of the grains into the surface of the substrate. The impact of the round blast grain on the base material causes a surface trace, the edges of which are pushed above the surface level. As a result of the tensile and compressive stresses which are induced in the scale layer, the integrity of the scale is disrupted at the point of impact, which largely contributes to their separation from the base material. [3-5]

A characteristic feature of the incident sharp-edged grains of the blasting means are the jams in the base material, where there is also the possibility of pushing the scale. Despite the fact that large grains have a larger thickness, it is possible to obtain a better quality blasted surface by the action of small grains, with better coverage of the surface with traces of falling grains. The paper deals with the optimization of technological parameters of the blasting process for the roughness of the metal surface, especially in terms of the choice of type and size of blasting agent.

2. Materials and methods

1. Planar surface characteristics – the evaluation in 2D

The experiment was performed on test specimens marked S235JR + AR. It is a hot-rolled structural steel with dimensions of 100x50x10 mm. The chemical composition of the material is given in Table 1.

Table 1: Chemical composition of materials S235JR+AR, wt. %

Fe	C	Si	Mn	P	S
99.04	0.154	0.179	0.416	0.006	< 0.002
Cu	Al	Cr	Mo	Ni	V
0.048	0.019	0.056	0.012	0.048	< 0.002

For the purpose of the experiment, the individual surfaces of the nine test specimens were blasted with three different types of blasting means. - metal blasting means of regular spherical shape - steel granulate steel shot - SS - is made of specially modified super-eutectoid steel. Its characteristic feature is a fine homogeneous structure, which is ensured by tempered martensite. This structure shows ideal resilience and good fatigue resistance of the material. - metal blasting means of irregular sharp-edged shape - steel grit steel grit - SG - is produced by crushing specially heat-treated grains of steel granulate.

This blasting means has a generally sharp-edged grain shape and is used for surface treatment and cleaning. - non-metallic blasting agent of irregular sharp-edged shape - brown corundum - brown corundum - BC - It is a synthetic material based on alumina (Table 2). It is used where a high quality blasted surface is required. Each of these blasting means was used at three different grain sizes. Table 2 shows the individual sample sizes and designations.

Table 2: Overview of types and designations of used blasting means

Blasting means	Medium grain size [mm]	Identification of the sample
Steel shot S280	0.85	SS1
Steel shot S330	1	SS2
Steel shot S390	1.18	SS3
Steel grit GH40/8	0.5 – 0.6	SG1
Steel grit GH25	0.85 - 1	SG2
Steel grit GH18/13	1.18 – 1.4	SG3
Brown corundum F30	0.5 – 0.71	BC1
Brown corundum F24	0.6 – 0.85	BC2
Brown corundum F20	0.85 – 1.18	BC3

The steel sheet samples required for the experiments were blasted using an Airblast ABSC 1440 pneumatic blasting machine. The blasted samples were then measured for roughness parameters using a Mitutoyo Surf test SJ-201 contact roughness tester. The surface classification in terms of roughness was performed in accordance with STN EN ISO 4287. The basic source of information is the surface profile, which is created by cutting the actual surface with a defined area. The parameters Ra - the middle arithmetic deflection of elaborated profile on the basic length, Rz - the largest height of the profile on the basic length, R_{Pc} - the average number of peaks per the average were evaluated.

The display of blasted surfaces of test specimens in 3D, realized by software, was performed for the purpose of a more detailed analysis of the character of blasted surfaces and in order to obtain their visualization. The scanning tip of the Surf test SJ-201 profilometer produces mutually parallel profile curves with a defined scanning spacing (0.1 mm perpendicular to the measuring

length), on the basis of which the resulting 3D interpretation of the surface is created.

3. Results

The values of the roughness parameters for surfaces blasted with different types of blasting means with different grain sizes are shown in Fig. 1.

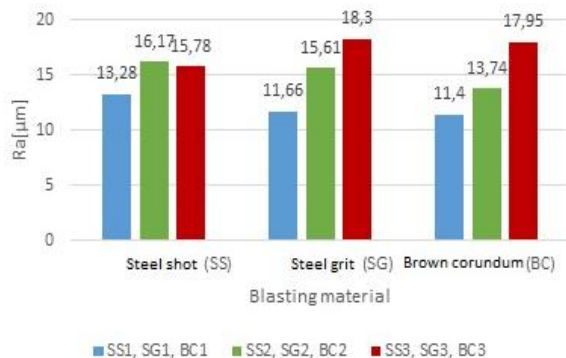


Fig. 1: Ra parameter values

From Fig. 1, it can be stated that the largest increase in the parameter Ra was found in samples blasted with steel grit and brown corundum. The increases were minimal in the samples blasted with steel granulate (SS1 - SS3). This fact can be explained by the type of blasting agent used in terms of shape, as well as by the gradation of the diameters of the individual blasting grains.

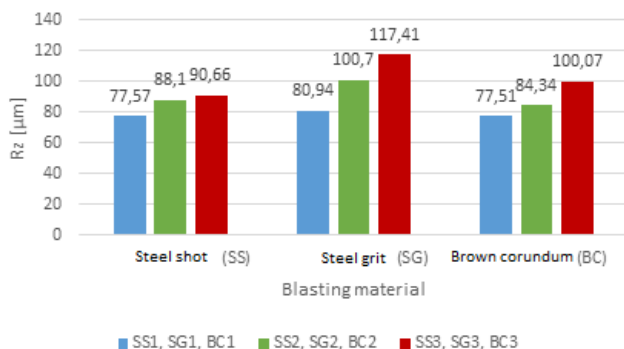


Fig. 2: Rz parameter values

The parameter Rz, according to Fig. 2, shows the largest increases in samples blasted with steel grit (SG). The course of samples blasted with steel granulate is similar to the parameter Ra.

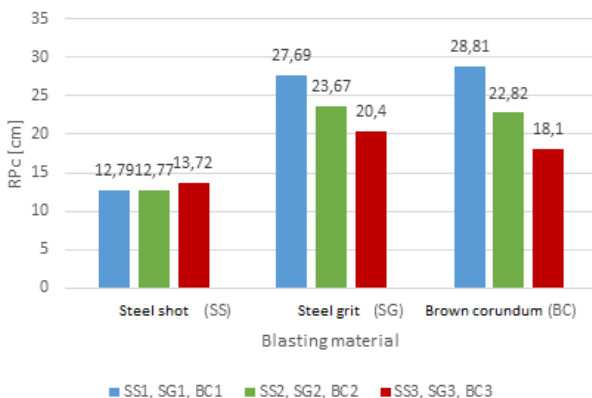


Fig. 3: RPC parameter values

In Fig. 3, the surface area was evaluated by the RPC parameter. Here it can be stated that the samples blasted with steel granulate do not show a significant change in surface fragmentation, which is caused by the use of a round type of grain. Samples blasted with steel grit and brown corundum showed more pronounced differences in segmentation using different grain sizes, with the most significant change occurring with brown corundum blasting.

The performed measurements on different types of blasted surfaces proved the unambiguous influence of the use of the type, size and shape of the blasting mean on the final character of the blasted surfaces in terms of roughness and articulation. Based on the measurements and their results, it can be stated that in addition to the characteristic Ra, which is the most commonly used quantity in the evaluation of surface roughness, it is necessary to qualify the evaluation of microgeometry with other characteristics, allowing more detailed definition such as Rz and RPC, or other suitable parameters (e.g. RSm). Visualization of surfaces using their 3D is shown in Fig. 4 - 9.

The views were created based on the processing of the measured data matrix using the MATLAB software. Imaging the surfaces of the test specimens by means of 3D and topographic images obtained on the basis of the measured values helps to improve the idea of the condition of the surfaces after blasting with different blasting means with different grain sizes. The effect of the shape and grain size of the blasting agent on the final character of the surface after blasting was also demonstrated by means of these images.

The sample surfaces blasted with steel granulate (spherical blasting agent) shown in Figs. 4-6, show typical, intersecting spherical canopies, the size of which depends on the grain size. Fig. 7-9 represent surfaces blasted with steel grit - a sharp-edged blasting agent, where greater articulation is visible.

This is due to deep jams in the base material, which is the result of sharp, uneven grains of crushed steel and brown corundum. The size of the clogs was determined by the grain size of the blasting means.

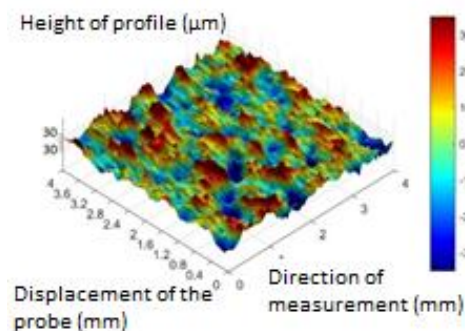


Fig. 4: 3D surface after blasting with steel shot - SS1

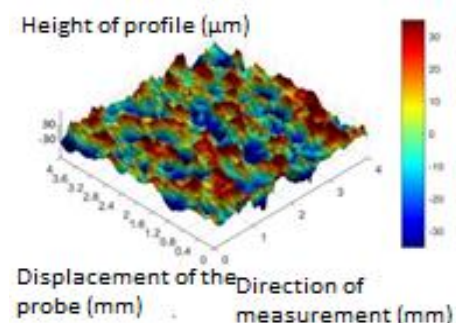


Fig. 5: 3D surface after blasting with steel shot - SS2

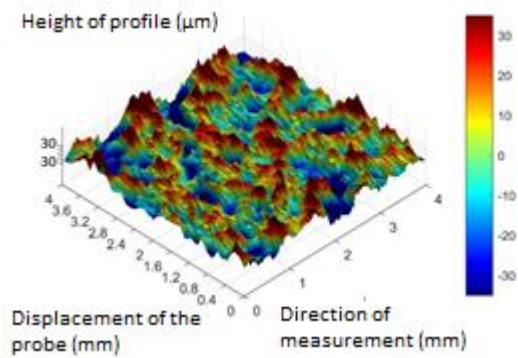


Fig. 6: 3D surface after blasting with steel shot - SS3

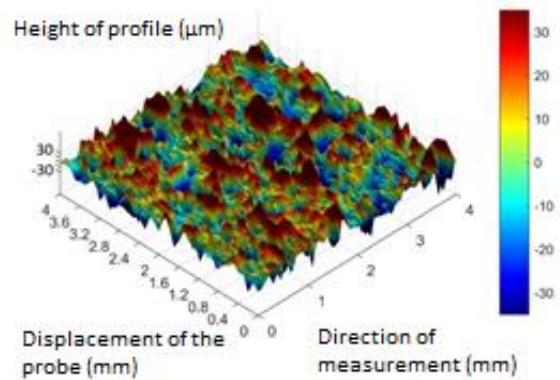


Fig. 9: 3D surface after blasting with steel grit - SG3

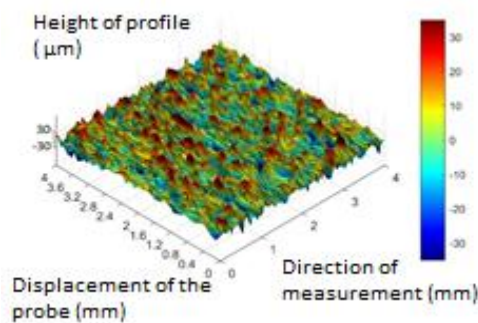


Fig. 7: 3D surface after blasting with steel grit - SG1

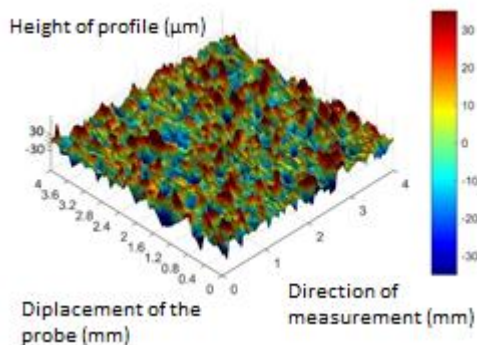


Fig. 8: 3D surface after blasting with steel grit - SG2

Conclusion

The essence of surface blasting, as a form of their mechanical pretreatment, lies in the creation of a new surface with new properties, which form a prerequisite for the ideal anchoring of subsequently applied coatings.

The quality of the blasted surface is determined primarily by the selected type of blasting means - (material, grain size and shape) and the blasting mode. The mentioned parameters form the basis for the blasting process and are chosen with regard to the subsequent use.

The surface after blasting shows characteristic features in terms of roughness and articulation, which are different when blasting with a sharp-edged and round type of blasting material. The surface blasted with sharp-edged grains (eg steel grit, brown corundum) does not show as uniformity as the surface blasted with round-shaped granules. For this reason, the more rugged surface after blasting is sharp-edged blasting means.

Such a surface is suitable as a surface under coatings, ensuring optimal surface cleanliness and adhesion of coatings.

Acknowledgement

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Improving the accuracy of electron-beam processing of small thickness optical plates

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Abstract: The article presents the results of increasing the accuracy of the operating parameters of the electron flow (power density, speed of electron-beam processing) in obtaining optical plates of small thickness as components of optical instrumentation devices. It is shown that flexible control of such parameters of tape electron flow allows to significantly (1.5-2 times) increase the accuracy and quality of surface processing of small thickness (up to millimeters) optical silicate plates (glass K8) by low-energy electron flow. The implementation of such management was carried out using an information-measuring system, the general principles and functional scheme of which are given in this article. The proposed system allows with high accuracy (relative error does not exceed 4.5%) and efficiency (the time between the moment of determining the parameters of the electron flow to the moment of its formation with the adjusted values of these parameters does not exceed 12-17 μ s).

KEY WORDS: ELECTRON-BEAM PROCESSING, LOW-ENERGY ELECTRON FLOW, SMALL THICKNESS OPTICAL PLATE, INCREASING THE ACCURACY, INFORMATION-MEASURING SYSTEM

1. Introduction

The Industry 4.0 initiative envisages the creation and development of automated production facilities, where all processes are managed in real time and taking into account changing external conditions [1]. Thus, the introduction of this initiative in the technology of creating components of modern optical microdevices and microsystems of precision instrumentation with the involvement of a promising method of electron beam processing, allows for high-efficiency and high-precision processing of optical plates (including small thickness optical plates) of silicate optical glass. The main advantages of the above technology are the ability to obtain defect-free surfaces with residual irregularities up to 5 nm with complete elimination of the near-surface defective layer [2]. However, the modes of such processing are selected by experimental studies and do not provide for the possibility of automatic controlled electron beam surface processing of optical plates to give them new functional properties, such as asphericity and hydrophobicity of optical microlens surfaces of modern projection systems.

The main factor in high-quality electron-beam processing of optical materials is compliance with the high accuracy of the operating parameters of the electron flow (power density, speed of electron-beam processing and others). Thus, [3] shows the possibility of controlling the energy distribution of the tape electron flow (the deviation from the specified distribution did not exceed 2-5%). However, the proposed scheme does not allow dynamic control of power distribution in the electronic tape, has low stability (temperature and heating time of the cathode significantly increases its resistance, which leads to a decrease in energy efficiency of the electron flow), which eliminates the possibility of automatic correction voltage.

A number of leading domestic and foreign scientists are working on the development of new methods and means of electron-beam processing of optical materials, such as: I.V.Yatsenko, V.S.Antonyuk, V.A.Vashchenko, G.V.Kanashevych, H.Bluhm, A.Kowalik, K.Góra and others [4-6]. However, despite the scientific achievements of these scientists, the issue of improving the accuracy of compliance with the operating parameters of the electron flow (power density, speed of electron-beam processing, etc.) in the dynamic process of obtaining optical plates of small thickness still remains.

Therefore, it is important to develop and apply an information and measurement system of the operating parameters of the tape electron flow to provide flexible control of these parameters in obtaining optical plates of small thickness.

The purpose of the study: to increase the accuracy of the operating parameters of the tape electron flow (power density, speed of electron-beam processing) by using information-measuring system that allows flexible control of these parameters, thereby improving the accuracy and quality of surface processing of optical silicate plates (K8 glass) of small thickness (up to millimeter units).

2. Features of processing of optical plates of small thickness by a tape electron flow

According to the authors' own experience [7], the processing of small-thickness optical plates can be carried out on an upgraded vacuum unit YBH-74, which includes heating and cooling furnaces, fittings for holding and moving objects, Pierce electron-beam gun with tungsten wire cathode (cathode diameter 0.4 mm, wire length 90 mm). At the heart of this technology is the fact that when incandescent, the cathode emits electrons that are accelerated by an electrostatic field, pass through the anode slit (slit length 80 mm, width can vary within 1-4 mm) and are directed to the sample. The scheme of control of the electron flow of the tape form in the processing of optical plates of small thickness is shown in Fig.1.

The electrical characteristics of the electron-beam gun are as follows: cathode heating current $I = 10-50$ A $\pm 15\%$; range of accelerating voltages - $U_{ac} = 0-10$ kV $\pm 2-3\%$; current stream range $I_s = 50-400$ mA $\pm 1-5\%$. The residual pressure in the vacuum chamber required for the operation of the gun is $p_0 = (3-5) \cdot 10^{-4}$ Pa. The distance from the electronic gun to the object of processing can vary from $H = 10-60$ mm ± 0.1 mm. Accelerating voltage up to 10 kV characterizes low-energy electron-beam processing and provides energy to electrons, which is enough to heat the surface of the optical material in vacuum to temperatures of 800-1500 °C. In this case, the surface of the material is melted by electron flow to a depth of 200 μ m, and the final stage of formation of the modified surface layer is the slow cooling of the treated sample according to a predetermined temperature law.

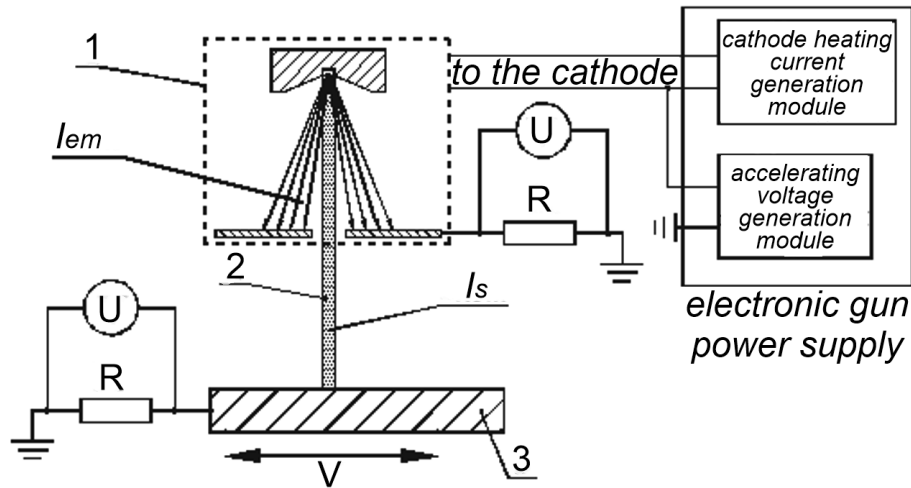


Fig. 1. Scheme of control of electron flow of a tape form at processing of small thickness optical plates: 1 - Pierce electron-beam gun, 2 - tape electron flow, 3 - a mobile platform, I_{stream} - current of an electron flow; I_{em} - cathode emission current

Based on the data of [8], where thin plates (1 mm thick) made of K8 silicate glass were used as experimental samples, it was found that the optimal processing speed of optical glass should not exceed 20 cm/s. The quality of processing of such samples by the above technology was determined by the state of the technological environment (residual pressure, heating and cooling temperature of products), perfection of processing tools – electronic gun and electron flow, as well as equipment and software that provide flexible and high-quality processing.

The source of electron radiation during tape electron-beam processing is a tungsten wire cathode with a diameter of 0.5 mm. The main operating parameters of the cathode include: emission current I_{em} , glow current cathode I , service life t , positioning accuracy and cathode efficiency η . At the same time, it should be noted that high cathode temperatures ($T = 2100-2200$ °C) and periodic contact with the atmosphere leads to erosion of its surface [9].

The feature of using a wire cathode is that the deviation of the width of the electron flow along the length is relative to the size of its central part, for distances $H = 10-40$ mm does not exceed 2-5%, which allows to classify the electron flow on the surface of the product as a tape.

During the research carried out in [10], it was determined that the term of effective operation of tungsten wire cathodes brand BA-1 with a diameter of 0.1-0.6 mm in terms of their use in the technology of electron-beam processing of optical materials is 40-120 hours. This time difference is due to the different physical states of the cathode surface and is determined by the operating temperature, emission current, wire diameter, electrical characteristics of the cathode load and the time of its contact with air during technological depressurization of the vacuum chamber. The effective operation of the cathode is determined by the period during which its diameter decreases by no more than 10% [11]. However, the decrease in cathode diameter is primarily due to the uneven evaporation of the material due to temperature instability along the wire. At the same time, such a change in the diameter and, accordingly, the physical characteristics of the cathode, leads to uncontrollability and uncontrollability of the processing process, which is unacceptable.

In the course of research, in [12] the dependences of the width of the thermal impact zone b , the central part of the thermal impact zone b' and the coefficient of concentration k_e from the distance to the object (metal strip) of H action were shown in Fig.2.

Such dependences are in good agreement with the results presented in [13] for medium-energy electron beams with a round cross-section. The zone of maximum energy action of the electron flow b' is explained by the presence of two maxima of the intensity of the electron flow, which is characteristic of the used electron-optical system.

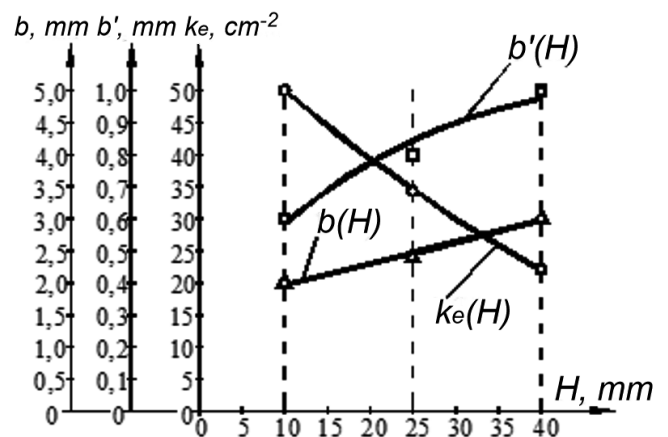


Fig. 2. Dependences of the width of the zone of thermal influence b , its central part b' and the coefficient of concentration of the electron flow k_e from the distance to the object of action of the electron beam gun H .

At the same time, under the same conditions of the influence of the electron flow on materials with different nature of electrical conductivity, it should be noted that the electron flow on dielectric materials (eg optical glass) has 1.5-2 times the width of the thermal zone. This is due to the surface polarization of the dielectric material by a concentrated stream of electrons, which in turn leads to the formation of an electron cloud above the surface of the material, which acts as a scattering electron lens.

Given the energy of electron beam processing, this expansion of the zone of influence of the electron flow on the dielectric material at a constant value of specific power leads to a proportional reduction of the maximum current density (compared to conductive materials) by 1.4-1.65 times. This opens up the possibility of using controlled electron flow for the implementation of high-precision low-energy processing of small thickness optical plates.

3. Quality management of optical products processing of optical products

To control the quality of the processing of small-thickness optical plates by electron flow, the energy distribution in the tape electron flow must be measured. To do this, the authors used a microprocessor device to sense the electron flow, in which the probes are located in parallel to each other, Fig.3.

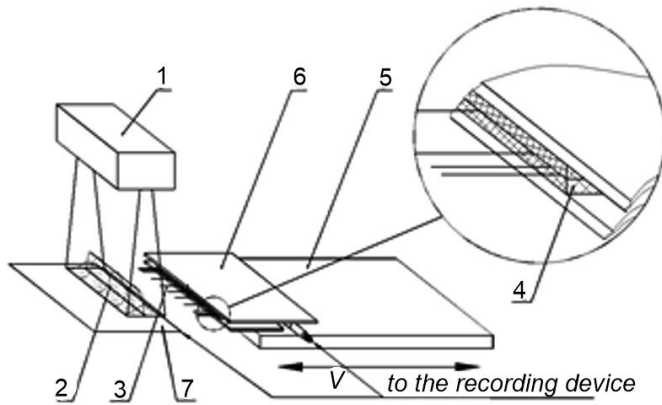


Fig. 3. Scheme of sensing the tape electron flow: 1 - module of Pierce electron-beam gun, 2 - tape electron flow, 3 - tungsten probes, 4 - ceramic insulator, 5 - movable platform, 6 - probe module, 7 - collector

To reduce the impact on the measurement results of the phenomenon of secondary electron emission, as well as to eliminate interference from electromagnetic waves due to the reflection of electrons from the surface, the probes are arranged in pairs with an offset in the direction of the probes.

Processing quality management was carried out as follows. In the process of switching on the rotating device, first, the sounding system came under the electron flow, and only after it - the processed products. The probe current from each probe through the copper wire and the vacuum electric input was recorded by an automated system located outside the vacuum chamber. The signal received by each of the probes changed as a result of the passage of the electron flow and was the result of integrating the current

distribution across its cross section. The current recorded by the sounding system was fed to the converter "current-voltage". Next, the control microcontroller was used to process the obtained data (calculate the difference of probe characteristics between paired probes → analog-digital conversion of the results due to current → conversion of currents to the cross-sectional area of the probes → differentiation of characteristics gun by adjusting the operating parameters of the electron-beam processing mode, for which the latter were formed by the microcontroller into data packets and transmitted to the control system.

The probe current, which is used to determine the current density distribution over the cross section of the electron flow (which, in turn, determines the quality of processing of optical products by electron flow), is converted into digital form by an automatic digital device and processed by a microprocessor according to the formula:

$$j(x) = (I(x) - I(x - \Delta x)) \cdot d \cdot V \cdot t,$$

where $j(x)$ is the current density at a given point with coordinate x ; $I(x)$ - probe current at this point; $I(x - \Delta x)$ - probe current during the previous measurement; d is the diameter of the probe; V - speed of the platform with probes; t is the period between measurements and data conversion by analog-to-digital converter.

As a result of calculations of probe characteristics of electronic tape according to the above formula and their comparison with experimentally obtained data (Fig. 4) proved the possibility of flexible control of electronic tape shape and, accordingly, the quality of processing optical products by electron flow.

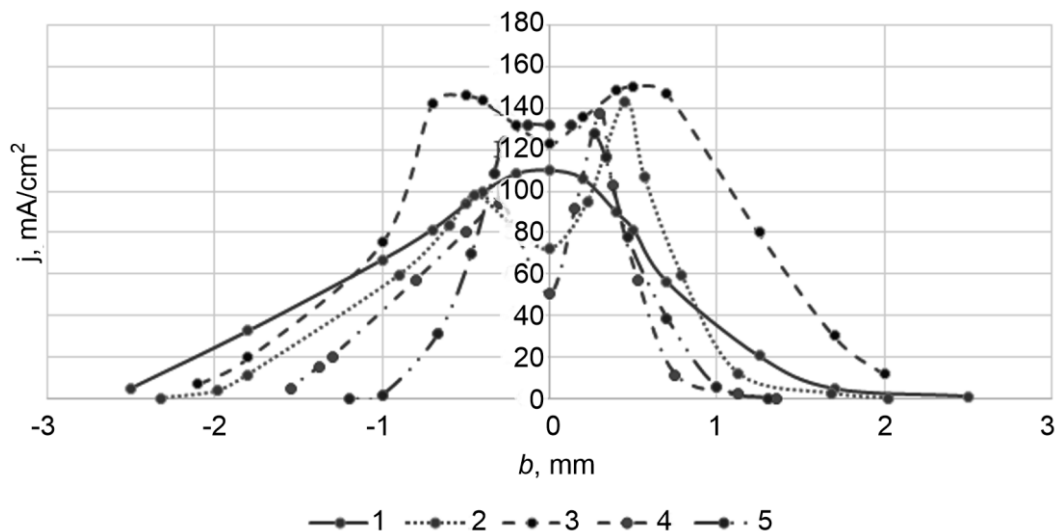


Fig. 4. Probe characteristics of the electron flow: the current density distribution is calculated on the basis of the probe current in the electron stream (solid lines) and obtained experimentally (points) for different modes of obtaining of small thickness optical plates ($U_{ac} = 3500$ V): 1 - $U_{mod} = 0$ V; 2 - $U_{mod} = 25$ V; 3 - $U_{mod} = 35$ V; 4 - $U_{mod} = 45$ V; 5 - $U_{mod} = 55$ V

4. Information-measuring system of working parameters of electron flow

During the research of the process of electron-beam processing of small thickness optical plates and in order to increase the accuracy of the operating parameters of the tape electron flow (power density, speed of electron-beam processing) was developed information-measuring system. The main tasks solved by this system:

- measurement of energy distribution density in the cross section of the electron flow with a power density of 100-1000 W/cm²;

- determining effective width of the electronic tape flow;
- identification of factors that affect the distribution of energy in the cross section of the electron flow;
- study of the parameters of the electron flow in the process of electron beam processing;
- presentation and transmission for further processing of the PC or the system of automatic control of the obtained results, which are converted into digital form directly for stabilization and control of the electron flow.

The scheme of the developed information-measuring system of working parameters of the electron flow is presented in Fig.5.

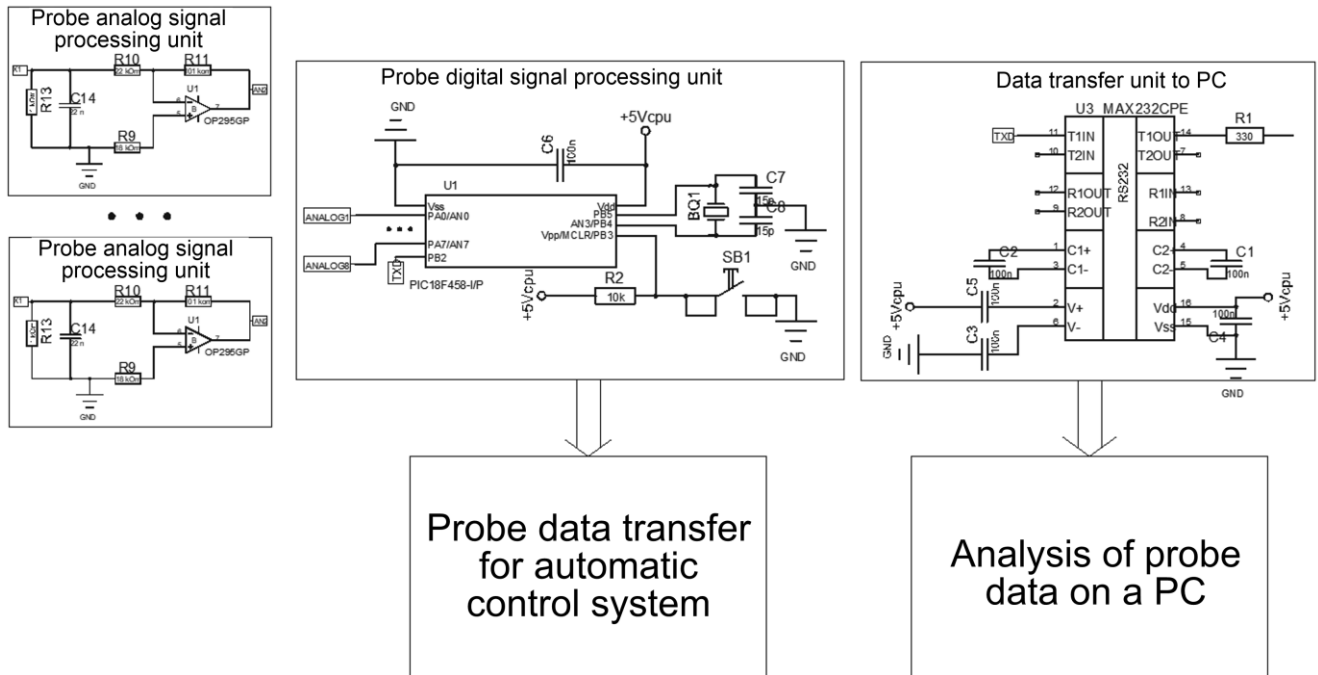


Fig. 5. Block diagram of the information-measuring system of the operating parameters of the electron flow

The peculiarity of this scheme is that the current recorded by the probe measuring system is fed to the converter "current-voltage", based on precision amplifiers OP-295.

Then, with the help of the control microcontroller, the received data used for e-gun control is processed by adjusting the operating parameters of the electron-beam processing mode, for which the latter are formed by the microcontroller into data packets and transmitted to PC via RS-232 interface and automatic control via CAN interface. The signal used to determine the distribution of current density in the cross section of the electron flow, using an automatic digital device is converted into digital form and processed by a microprocessor that performs numerical differentiation of the measured characteristic. In this case, the time between the determination of the parameters of the electron flow to the moment of its formation with the adjusted values of these parameters does not exceed 12-17 μs , which guarantees high efficiency of its work.

Thus, an information-measuring system has been developed that provides flexible control of the operating parameters of the tape electron flow (power density, speed of electron-beam processing) when processing the surface of optical silicate plates (glass K8) of small thickness (up to millimeters).

5. Discussion of information-measurement system test results

As a result of experimental tests developed by the information-measuring system, the values of the operating parameters of the tape electron flow were obtained and studied, according to which the electron flow current distributions on the anode and dielectric material were constructed (K8 optical glass). The dependences of the electron current I_s on the accelerating voltage U_{ac} at different values of the width of the anode gap and the heating current of the cathode I , Fig.6-8.

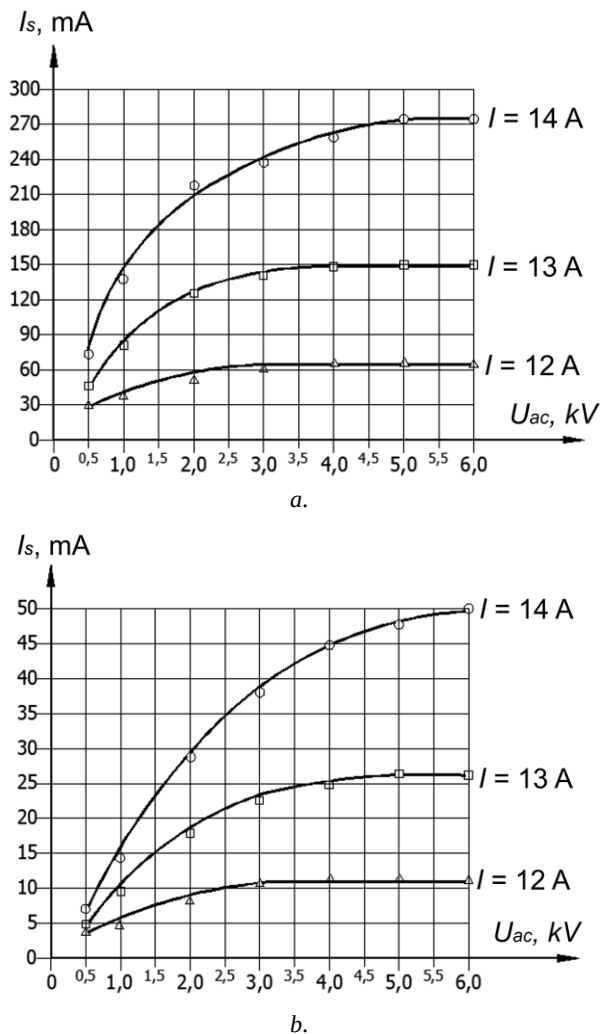


Fig. 6. Dependence of the current stream I_s on the accelerating voltage U_{ac} at the cathode (a) of Pierce electron beam gun and on the glass plate K8 (b). Anode slit width $b_a = 2.0$ mm, the area of the impression on the optical plate from the action of the electronic tape 4.0 mm $\times$ 90 mm.

As can be seen from Fig.6 for the optimal geometric parameters of the Pierce electron-beam gun, which were given in [14], namely: at the width of the anode gap $b = 2.0$ mm, the dependence of the electron current on the accelerating voltage, as on the cathode of the electron gun, and on the glass plate have high stability in the range of accelerating voltage 3-6 kV and processing current of 30-180 mA (on the anode) and 5-30 mA (on the dielectric) at a cathode current of up to 13 A, which corresponds to the main technological modes of low-energy electron-beam processing of dielectrics (including optical glass). Such modes correspond to the structural modification of the surface layer of dielectrics in which there is a complete remelting of fractured and defective layers resulting in the formation of a new surface in terms of chemical structure and physical properties. The basic technological modes of electron-beam processing of products from optical glass are based on such modification.

For comparison, Fig. 7, 8 shows the volt-ampere characteristics for the anode slit width $b = 1.5$ mm (Fig. 7) and $b = 3.0$ mm (Fig. 8).

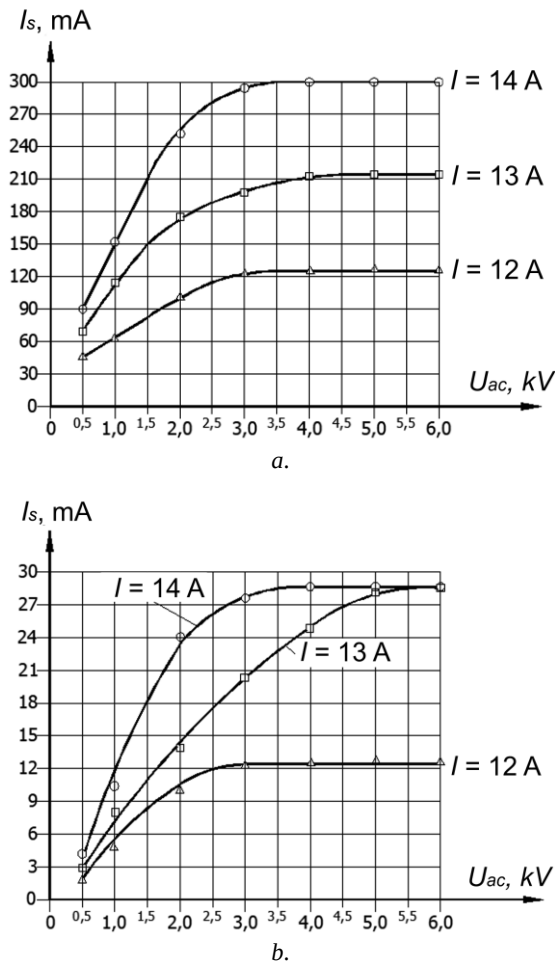


Fig. 7. Dependence of the current stream I_s on the accelerating voltage U_{ac} at the cathode (a) of Pierce electron beam gun and on the glass plate K8 (b). Anode slit width $b_a = 1.5$ mm, the area of the impression on the optical plate from the action of the electronic tape 2.7 mm $\times$ 90 mm.

Figure 7 shows the volt-ampere characteristics on the cathode of the electron gun and on the plate made of glass K8 at the value of the anode gap $b = 1.5$ mm. The results of the study of these volt-ampere characteristics indicate high stability in the range of accelerating voltage 3-6 kV and processing current 30-300 mA (at the anode), while the dielectric stable value of accelerating voltage is observed only in the range of processing current 5-15 mA, which corresponds only to the modes of electron-beam processing, characterized by heat processing of surfaces, which is carried out without the formation of a liquid phase.

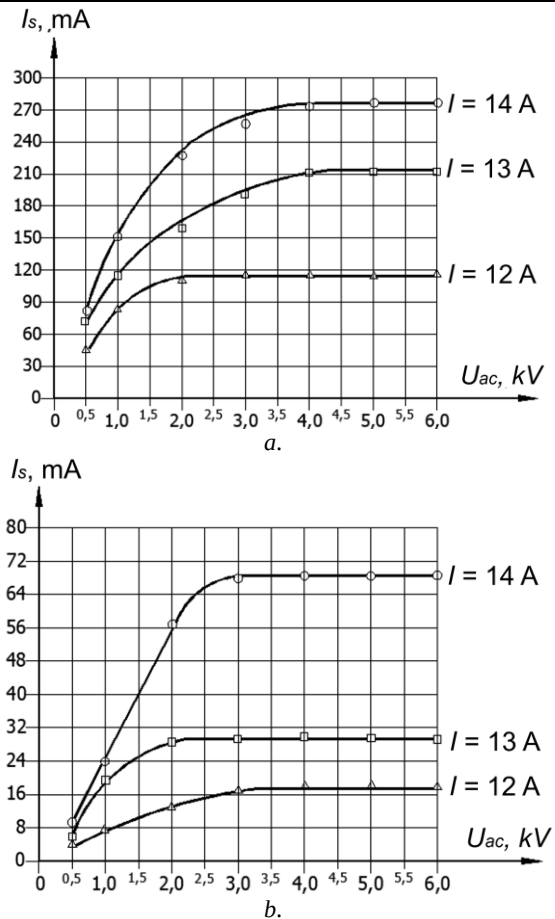


Fig. 8. Dependence of the current stream I_s on the accelerating voltage U_{ac} at the cathode (a) of Pierce electron beam gun and on the glass plate K8 (b). Anode slit width $b_a = 3.0$ mm, the area of the impression on the optical plate from the action of the electronic tape 6.0 mm $\times$ 90 mm.

At the same time, at the value of $b = 3.0$ mm (Fig. 8), high stability, as in the case of $b = 2.0$ mm (Fig. 6), is observed in the range of accelerating voltage 3-6 kV and incandescent current cathode

12-14 A. The electron current at the anode is in the range of 30-300 mA, while the dielectric values of the processing current increase to 16-70 mA, which corresponds only to the modes of electron beam processing, which is intense evaporation and boiling of the substance of the surface layer of optical glass, and its practical use is unpromising and extremely limited.

In general, the energy modes of processing, which were obtained by studying the operating parameters of the tape electron flow (power density, speed of electron-beam processing) through the use of information-measuring system, allow to choose modes of flexible control of electron-beam processing changes in other parameters of electron-beam processing (for example, processing speed) and degradation processes that occur at the cathode due to heating temperature and the influence of external conditions (in particular, the atmosphere). This allows you to significantly (1.5-2 times) increase the accuracy and quality of surface processing of optical silicate plates (glass K8) of small thickness (up to millimeters). Thus, after electron-beam processing (in optimal modes) of optical samples, the surface condition of these samples and its residual micro-irregularities were compared with the results of electron-beam processing of control group samples obtained according to the scheme without using the developed information-measuring system. As a result, the reduction of residual surface microroughness for optical glass K8 from 40-110 nm to 3.3-15.8 nm (electron-beam processing without the use of the developed information and measurement system) and up to 1.5-6.5 nm - radiation processing according to the control modes obtained by the developed information and measuring system), Fig.9.

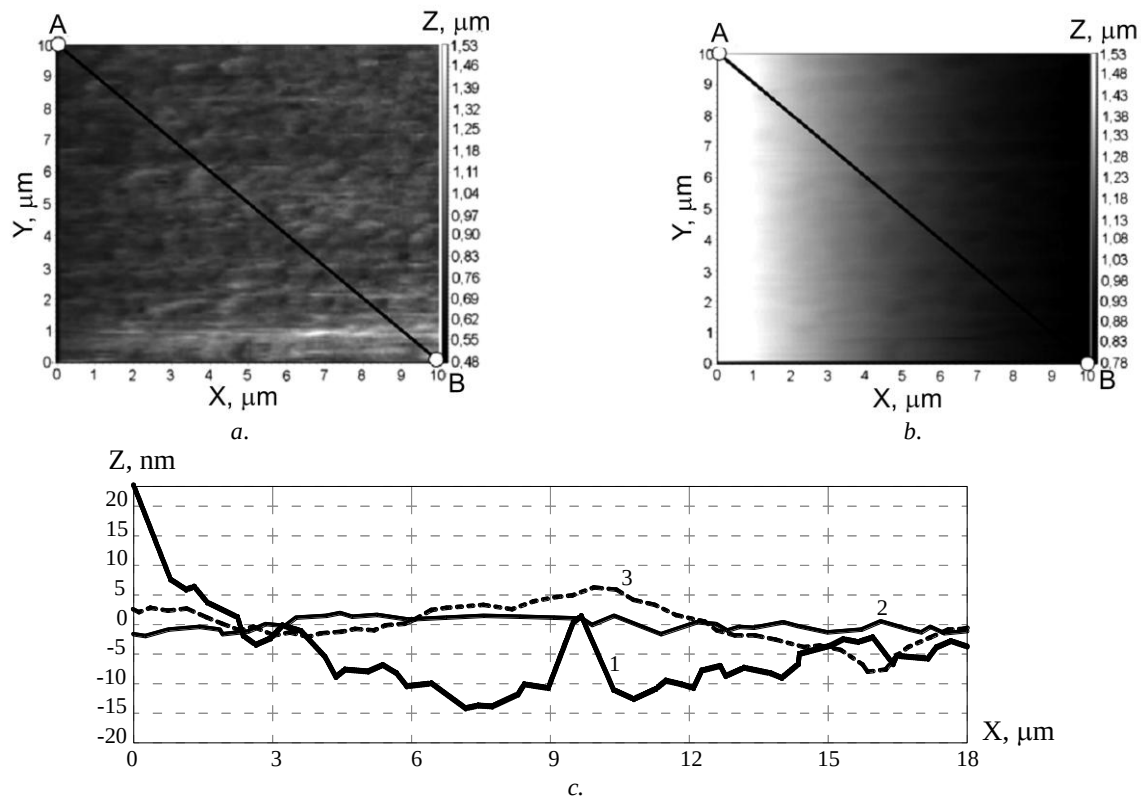


Fig. 9. Microgeometry (a, b) and profile along the line A-B (c) of the surface area ($10 \times 10 \mu\text{m}$) of a thin plate of K8 glass, which was treated by electron flow without (a) and using the developed information-measuring system (b) : 1 - profile of the output surface; 2 - profile of the surface treated with electron flow; 3 - profile of the surface treated by the electron flow using the information-measuring system of the electron flow operating parameters

Thus, the application of the developed information-measuring system allows to increase the accuracy (relative measurement error does not exceed 4.5%) of the operating parameters of the tape electron flow (power density, speed of electron-beam processing) and the quality of surface processing of optical silicate plates (glass K8) small thickness (up to millimeters), which provides flexible control of the process of such processing. In this case, it is experimentally proven that an uncontrolled increase, for example, the speed of movement of the electron flow on the treated plane-parallel surface, reduces the quality of such a surface (leads to the formation of wavy and aspherical on the surface). An uncontrolled increase in the specific energy power of electron-beam processing, for example, from 80 W/cm^2 to 150 W/cm^2 leads to the formation of microcracks on the surfaces with subsequent destruction of optical samples.

6. Conclusion

The results of increasing the accuracy of the operating parameters of the electron flow (power density, speed of electron-beam processing) in obtaining optical plates of small thickness as components of optical instrumentation devices are presented.

It is shown that flexible control of the operating parameters of the tape electron flow can significantly (1.5-2 times) increase the accuracy and quality of surface processing of small thickness (up to millimeters) optical silicate plates (glass K8) by low-energy electron flow.

The implementation of such control was carried out using the developed information and measurement system, which allows to determine and adjust the operating parameters of the tape electron flow in the processing of small thickness optical plates with high accuracy in real time (relative error does not exceed 4.5%) and efficiency (time between determining the parameters of electron flow to the moment of its formation with adjusted values of these parameters does not exceed 12-17 μs).

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Optimization of joining parameters of thin-walled materials by flowdrill technology

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Abstract: This paper deals with the investigation of the effect of speed on the form fit joint of dissimilar materials. Thin-walled materials based on steel and aluminium alloy were joined by thermal drilling. The shape and size of the resulting bushing were evaluated. It turned out that the best material combination for joining by flowdrill technology are joints made of steel and aluminum alloy. Aluminum alloy must always be placed in the bottom position. The best parameters of the formed bushing were achieved with the combination of DC-Al or TL-Al materials, at tool speeds of at least 2400 rpm.

Keywords: JOINING, FLOWDRILL, THIN-WALLED METAL SHEETS, STEEL, ALUMINUM

1. Introduction

Minimizing emissions in transport is a dominant theme today. In order to meet this objective, conventional steels are being replaced by non-conventional high-strength steels, which make it possible to reduce the cross-sections of components and the weight of the whole, as well as to save raw materials. Furthermore, steels are being replaced by other materials with good specific strength, such as aluminum, magnesium alloys or even composites. The individual parts of vehicles are assembled in a customized manner and hence there is a need to address the joining of dissimilar materials that differ from each other by their very nature - the internal arrangement of the constituent units, microstructure, mechanical, physical properties as well as the nature of the response of these materials to different types of loads [1-12]. Joining dissimilar materials by welding encounters problems especially in joints between steel and aluminum, which are associated with insolubility of the elements and formation of brittle intermetallic compounds. Adhesive bonding solves many of these problems, but the joints have a limited temperature of use and slow down the production cycle of the component due to the time required for the adhesive to cure. A promising joining technology is mechanical joining with one of the many variations of clinching or riveting. These technologies are already fairly well studied, but require in many cases a two-sided approach to the parts to be joined.

Schmerler et al. [13] in their publication dealt with the idea of joining materials by thermal drilling technology, although this technology is not primarily intended for this purpose. The idea is based on the premise that if two or three thin-walled materials are layered on top of each other and drilled with a flowdrill tool, coaxial bushings could be formed, mechanically wedged together, which could form a form-fit joint. This possibility was also tested by Guzanova et al. in [14], using thermal drilling technology to form joints between pairs of dissimilar materials based on steel and aluminum alloy. They found that the best joints were formed when one of the materials was an aluminum alloy placed in the bottom position. It also showed the relationship of the bushing formation with the thermal conductivity of the materials. However, the joints were formed at constant parameters. Therefore, there was a need to test other process parameters, in particular rotational speed and its effect on the formation of the joint bushings.

The paper therefore aims to test the effect of rotational speed on the size and shape of the bushings formed during the thermal drilling of a pair of thin overlapped plates, where the intended joint is always to be formed from a pair of dissimilar materials. This should result in the determination of the appropriate rotational speed for the successful formation of joints from dissimilar materials.

2. Materials and methods

The following materials were used for the joints formation:

- Cold rolled uncoated deep drawing steel DC04, used for the production of interior and exterior parts of car bodies and for other stampings, thickness 0.8 mm, next denoted as **DC**.
- Zinc-galvanized fine-grained high-strength low alloyed steel TL 1550-220+Z with increased cold formability, thickness 0.8 mm, next denoted as **TL**.
- Precipitation hardened aluminum alloy EN AW-6082 T6 (AlSi1MgMn), thickness 1.0 mm, next denoted as **Al**.

The chemical composition of materials, their mechanical properties and surface conditions are given in Tables 1-2.

Table 1: Chemical composition of materials, wt. %.

DC									
C	Mn	P	S	Fe					
0.04	0.25	0.009	0.008	bal.					
TL									
C	Mn	Si	P	S	Al	Nb	Ti	Cu	Fe
0.10	1.00	0.50	0.08	0.03	0.015	0.10	0.15	0.20	bal.
Al									
Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al	
1.00	0.40	0.06	0.44	0.70	0.02	0.08	0.03	bal.	

Table 2: Mechanical properties and some specific conditions of materials.

materials	YS [MPa]	UTS [MPa]	Elongation [%]	Thickness [mm]	condition
DC	197	327	39	0.8	electrostatically oiled
TL	292	373	34	0.8	Zn coated, 100 g·m ⁻²
Al	290	340	14	1.0	solut. treated, artificially aged

The shape and dimensions of the test specimens were designed according to EN ISO 12996 depending on the thickness of the materials to be joined and the diameter of the tool used, Fig. 1. Flowdrill Long ø 5.3 mm thermal drilling tool was selected for joints formation.

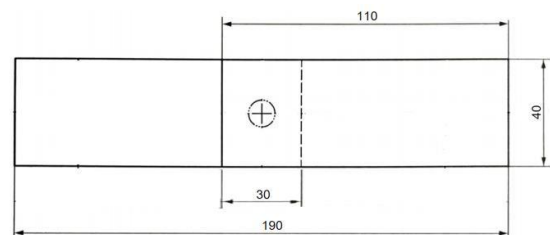


Fig. 1 Shape and dimensions of joint assembly

The joints were created in manual mode using radial drilling machine, where the only variable was tool rotational speed. Tool

feed rate towards the material was implemented manually. The rotational speeds used were 1900, 2400 and 3800 rpm.

The formed joints are intended to be tested for shear strength under tensile stress in the next step, but this paper mainly presents a metallographic study of the formed bushings. This is because the material properties and thickness of the bushing formed from the top material in the joint will determine the load carrying capacity of the joint. Since the position of the materials in the joints is important, the material combinations were constructed according to the following scheme, Table 3.

Table 3: Matrix of created joints.

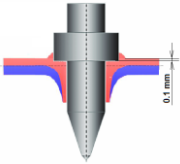
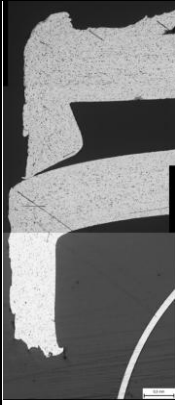
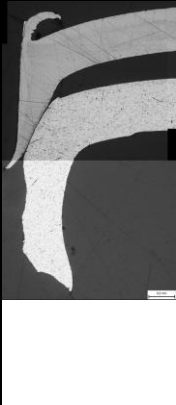
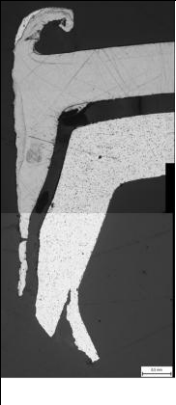
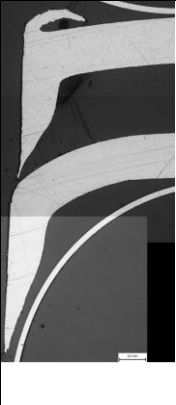
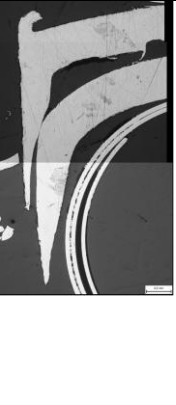
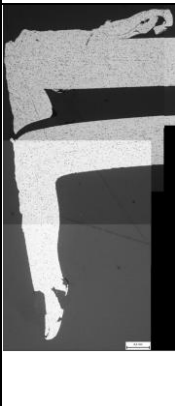
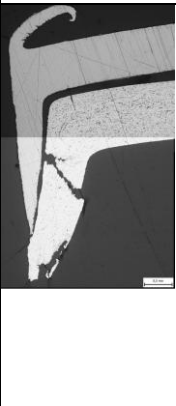
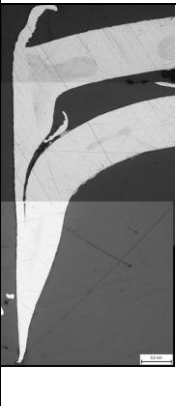
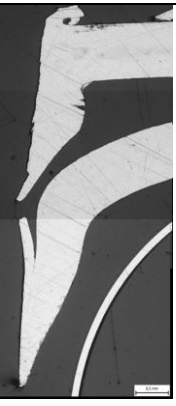
Positioning materials in the joint	Mat. in upper position	Mat. in lower position
	DC	TL
		Al
	TL	DC
		Al
	Al	DC
		Al

Table 4: Metallographic cross-sections through joints – one side view (right).

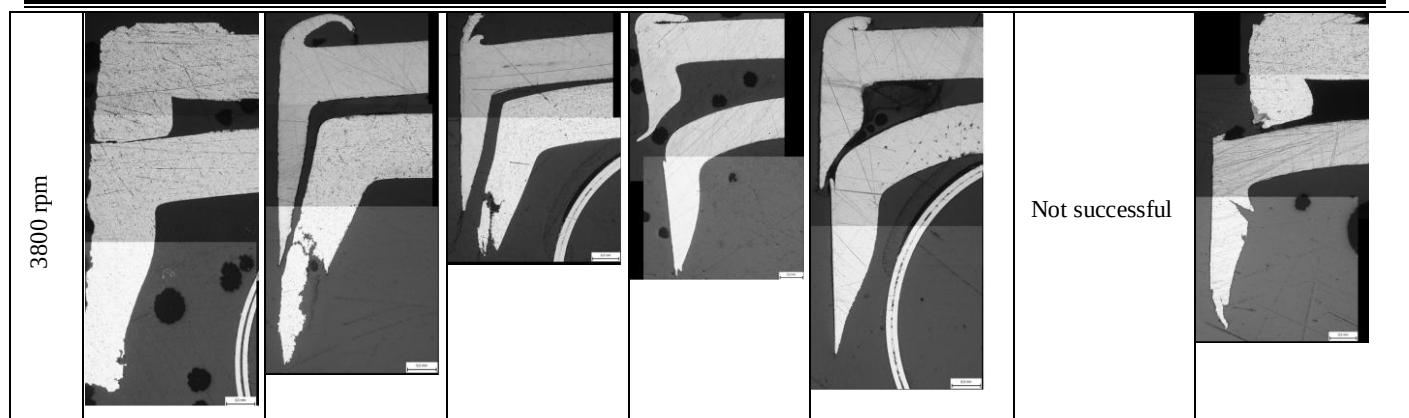
Rotation speed	Al-Al	DC-Al	TL-Al	DC-TL	TL-DC	Al-DC	Al-TL
1900 rpm						Not successful	Not successful
2400 rpm							Not successful

3. Results

The joints formed according to Table 3 were cut in the axis of the hole, embedded in resin and ground for macroscopic observation and measurement of the thickness of the formed bushings. The individual metallographic sections are shown in Table 4. In order to save space, only one side of the joint is always shown in Table 4.

Table 4 shows the following findings:

- Joints where Al is in the top position (Al-Al, Al-DC, Al-TL) are characterized by the fact that the plates are pushed apart by the bushing of the top material, there is no formation of two concentric bushings, thus no joint is formed and this regardless of the rotational speed. Due to its mechanical and physical properties, Al cannot be placed in the top position in the joint. Although its mechanical properties are at the level of TL steel (see Table 2), heating of Al due to frictional heat reduces the mechanical properties rapidly. Al is thus pushed laterally away from the hole location instead of forming a bushing.



- Joints formed from dissimilar steel materials (DC-TL, TL-DC) also do not exhibit suitable properties. From the metallographic sections it can be seen that the inner bushing formed from the top material thins very intensely towards the bottom material, which seems to cause a low load carrying capacity of the joint. In addition, a strong springback effect is evident, which will cause separation of the materials to be joined after the tool cycle is complete. This also does not contribute to the load carrying capacity of the joint. This phenomenon appears for both steel combinations (DC-TL, TL-DC) and at all three rotational speeds tested.
- The most successful joints have been made between steel and aluminum (DC-Al, TL-Al) when the aluminum alloy is in the bottom position. The inner bushing is formed from the upper steel stronger material and the aluminum alloy, softened by the frictional heat transferred from the steel, is shaped by copying the emerging steel bushing. Contact between the Al and the tool does not appear to occur at all. The springback effect is minimal. The thickness of the steel bushing is between 0.5 - 0.7 mm, which is a good result considering the thickness of the steel plate (0.8 mm). These connections are expected to have the highest load carrying capacity and energy dissipation, which is also an important indicator of the connections, especially for automotive applications.
- The effect of rotational speed was evident only in steel-aluminum joints (DC-Al, TL-Al). For DC-Al joints, the height of the steel bushing increases with increasing rotational speed. The bushing in the DC-Al joint formed at 1900 rpm is poorly formed and may slip out of the aluminum alloy under shear tensile stress. For this reason, a minimum speed of 2400 rpm may be recommended for the DC-Al joint. In contrast, the TL-Al coupling has developed a steel bushing with the greatest thickness just at 1900 rpm. At higher speeds, the steel bushing is thinner.

4. Conclusions

The paper presents the results of testing the effect of changing the rotational speed of the tool on the nature of joints formed between dissimilar materials by means of thermal drilling without the use of a screw. Form fit joints are formed based only on the mechanical forming of concentric bushings and their mutual interference. It is found that the joint can only be formed between steel and aluminum alloy. However, the aluminum alloy must be placed in the bottom position. Then the load capacity of the joint will depend on the internal (steel) bushing - its thickness and mechanical properties. The outer bushing made of aluminum alloy will only have a supporting function when the joint is loaded. The best parameters of the formed bushing were achieved with the combination of DC-Al or TL-Al materials, at tool speeds of at least 2400 rpm.

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Properties of polymer composites with long fibers

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Abstract: The paper is focused on composite materials with a polymer thermosetting matrix reinforced with long (continuous) fibers. These materials offer their specific properties that can be used in various areas of industry. From this point of view, polymer matrix composites are, due to their mechanical properties and low weight, the most promising material for use in various application solutions. However, their disadvantage is the high price, which is higher than the price of conventionally used materials. The method of production of components from composite materials itself requires precisely specified technological procedures, which differs slightly from the traditionally used methods of component production, e.g. of metal materials.

Keywords: COMPOSITES, PROPERTIS, REINFORCED COMPOSITES, MATRIX COMPOSITES

1. Introduction

The current worldwide trend in automotive production is to reduce the weight of cars, which allows carmakers to fulfill their intention to intensively reduce fuel consumption and thus the production of harmful emissions. The issue of composite materials is very extensive and concerns not only the automotive industry. It accompanies developments in land, air and water transport.

The application possibilities and uses of composites are diverse. They are becoming more widespread, also due to their excellent mechanical properties due to their weight. These materials offer their specific properties that can be used in various areas of industry. From this point of view, polymer matrix composites are, due to their mechanical properties and low weight, the most promising material for use in various application solutions. However, their disadvantage is the high price, which is higher than the price of conventionally used materials.

The method of production of components from composite materials itself requires precisely specified technological procedures, which differs slightly from the traditionally used methods of component production, e.g. of metal materials. Glass, aramid or carbon fibers are used to reinforce the polymer matrices to increase the stiffness of the composite. The size of the particles added to the matrices is a significant factor. Likewise, the direction and orientation of the fibers, or the amount of reinforcement, will affect the resulting properties. This offers the possibility to set the parameters and properties of the composite to best suit the specific conditions in which the component will be used.

2. Characteristics of composites

Composite materials are made of two or more materials with different physical, chemical and mechanical properties. The final material created by combining these components has significantly better properties than the properties of the individual components.

The selection of the individual components of the composites takes into account the conditions under which the composite will be used, such as the required strength, durability or its service life. The separate components of composites, generally called components, are divided into a matrix and a filler. [1]

Distribution of composite materials

According to the nature of the composite matrix, we divide it into the following groups:

- with a metal matrix,
- with non-metallic matrix:
 - organic materials: polymer matrix,
 - inorganic materials: ceramic matrix.

Metal matrices are characterized by ductility and toughness compared to polymer matrices. Metal matrices are most often made

of aluminum, magnesium and titanium alloys. For use at high temperatures, metal matrices are made of nickel alloys.

The main advantage of polymer matrices in composites is their low density, which is one of the main areas of their use in aircraft construction. One of the disadvantages is the low thermal stability of the polymers. The most important composites have thermoset matrices, such as polyester and epoxy resins.

Ceramic matrix composites are light and very hard materials, but they are very brittle. However, they can be used in environments with very high temperatures. Ceramic matrix composites can be oxidic or non-oxidic in nature. [3]

According to the geometric shape of the reinforcement, the composites are divided into:

- particulate,
- fiber: - with short fibers,
 - with long fibers,
- skeletal.

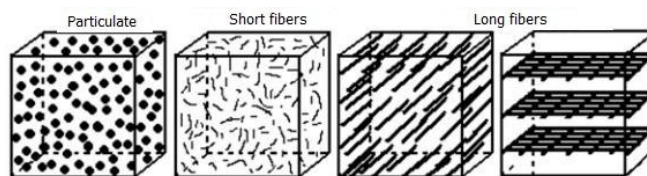


Fig. 1 Types of reinforced composites [2].

In the case of particulate composites, one dimension of the reinforcement structure does not significantly exceed the other dimensions. The reinforcing particles may have a spherical, plate-like, rod-shaped and irregular shape.

Fiber composites have reinforcement structures in one direction significantly larger than in the other. Short fiber composites have a significantly longer fiber length compared to the size of the product. On the contrary, for long fiber composites, their length is comparable to the size of the product.

The skeletal composites are formed by a porous matrix which is permeated by a continuous supporting skeleton. [2, 4]

According to the direction of the fibers in the matrix, the composites are divided into:

- unidirectionally short or long fibers,
- two-way or multi-way reinforcement,
- random orientation fibers: - short,
 - long. [4]

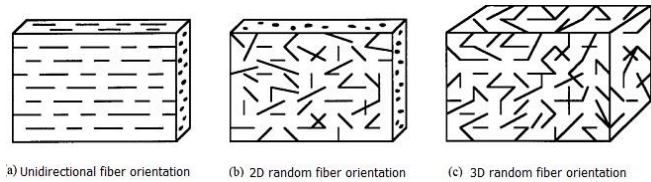


Fig. 2 Example of reinforced fiber orientation [5].

2D random orientation of fibers occurs in composites made by the method of pressing thin-walled components or in composites from mats. 3D random fiber orientation occurs in composites produced by injection molding or extrusion. In a composite material with randomly oriented fibers, we can speak of isotropy, so its properties are independent of the orientation of the fibers. The disadvantage is that one-way orientation of the fibers can occur, making the material anisotropic. [5]

According to the reinforcement material we know:

- metals,
- non-metals: - inorganic: - ceramic material,
 - glass,
 - Ad basalt,
- organic: - polymers,
 - polyamide fibers, kevlar,
 - nylon. [4]

The fibers can be man-made, natural (glass, carbon, aramid, basalt and others) or other reinforcing materials. The role of the fibers is to provide the matrix with the required strength and stiffness, thus helping it to resist cracks and fissures. [1]

3. Properties of polymer composites with long fibers

The current trend in the automotive sector is to reduce weight, which directly contributes to reducing fuel consumption and thus to reducing the emissions that cars produce. From this point of view, polymer matrix composites are the most promising material due to their mechanical properties and low weight. However, their disadvantage is the high price, which is higher than the price of conventionally used materials.

Each of the polymer composites has properties that make the composites more attractive for use in automotive manufacturing than conventionally used materials. These features include at least one of the following:

- high strength, • corrosion resistance,
- high rigidity, • high strength to weight ratio,
- high ductility, • low maintenance,
- thermal properties, • resistance to weather conditions,
- low weight, • good resistance to cracking,
- chemical resistance, • versatile use. [1]

Today, there are a large number of polymer-based composites. These materials are based on the combination of reinforcement and macromolecular material in order to improve mechanical properties. Many of the properties of composite materials depend on the appropriate combination of matrix type, reinforcement used, and manufacturing process.

The basic component of the composite matrix is a polymer that binds the filler of organic or inorganic origin. The matrix is divided into thermosetting and thermoplastic in polymer composites.

According to the most important manufacturers, the most commonly used thermoset and thermoplastic matrix types include the following:

THERMOSETS

- unsaturated polyester (UP),
- vinyl ester (VE),
- unsaturated epoxide (EP),
- polyamide (PA),

THERMOPLASTICS

- polypropylene (PP),
- polyamide (PA),
- polycarbonate (PC). [1, 6]

The properties of the most commonly used thermoplastic and thermosetting matrices can be seen in the following table.

Table 1: Overview of matrix properties [6]

Matrix type	Density [g/cm ³]	Young's modulus [GPa]	Tensile strength [MPa]
Thermosets	1.1 - 1.67	1.3 - 6.0	20 - 190
Polyesters	1.1 - 1.5	1.3 - 4.5	45 - 85
Epoxies	1.1 - 1.4	2.1 - 6.0	35 - 90
Vinyl esters	1.05 - 1.2	70 - 90	3.5 - 4.5
Polyamides	1.2 - 1.9	3.0 - 3.1	80 - 190
Thermoplastics	0.9 - 1.45	1.0 - 4.0	20 - 250
Polypropylene	0.9	1.1 - 1.5	28 - 41
Polyamide	1.42	2.8 - 3.4	76 - 83
Polycarbonate	1.21	2.1 - 2.8	62 - 76

Polyester matrix composites

Polyester resins are the most widely used resin systems in the shipbuilding industry. They are also used in the construction industry and for the production of common structural composite parts. The basic types of unsaturated polyester resins are:

- orthophthalic - lowest price. average properties.
- isophthalic - better than orthophthalic. better chemical and thermal resistance.
- fumaric - good chemical and thermal resistance.
- chlorophthalic - is non-flammable. but mechanical properties are worse than other species.
- vinyl ester - very good chemical and thermal resistance.

Unmodified and unsaturated polyester resins have a high shrinkage during curing, which is in the range of 7 to 8%. They are fragile and easily create microcracks, which are an undesirable element. The electrical properties are very good, as is the resistance to ultraviolet radiation. The resins saturate the fibers well, but the bond strength of the matrix and the glass fiber is lower. [7]

For processing, it is necessary for the resin to contain still other substances, such as catalyst, accelerator, additives, and chemical refractories. In order to achieve the best material properties, it is necessary to add the accelerator and the catalyst in well-measured amounts according to the ratios given for the individual resins. An excess of catalyst causes a shortening of the gelation, while its lack causes insufficient curing. Fillers are added in amounts up to 50% by weight of the resin, but some additives can affect the flexural and tensile strengths of the laminates. The description and suitability of the selected polyester resins can be seen in Table 2 below. [7]

Table 2: Selected polyester resins from HAVEL COMPOSITES CZ s.r.o.

Polyester resin	List
HAVEL pol. 1	Basic orthophthalic resin, which is pre-accelerated.
HAVEL pol. 2	Standard orthophthalic, pre-accelerated, low-emission and thixotropic resins.
HAVEL pol. 4	Clear, UV stable and non-accelerated resin.
HAVEL pol. 5	Non-accelerated resin suitable for the production of more demanding parts.
HAVEL pol. 6	Standard orthophthalic pre-accelerated resin with a lower price. It is suitable for the production of structural parts of ordinary fiberglass, where price is the main criterion.
HAVEL pol. H 834	It is a moderately reactive thixotropic resin that is pre-accelerated with low shrinkage. It is designed for the production of ships and other composite parts. It is suitable for production by spraying or manual laying. It has a high heat stability up to 95 °C

Vinyl ester matrix composites

Vinyl ester resins have a molecular structure similar to polyester, but primarily differ in the position of their reactive sites, which are located at the ends of the molecular chains. They are easy to handle, especially at room temperature, while providing mechanical properties comparable to epoxy resins.

Compared to cheaper polyester resins, they have better chemical resistance, including hydrolytic stability, which contributes to easier control of curing time. Polyester resins have poorer resistance to water and other chemicals, corrosion resistance and lower heat resistance. However, their price is lower compared to vinyl ester resins and they cure faster. They are used in the production of gas pipelines, cooling towers, shipbuilding and rotor presses.

In general, vinyl ester resins, which are unsaturated thermoset resins, combine the best properties of polyester and epoxy resins. [6, 7]

Epoxy matrix composites

Epoxy resins outperform most other types of resins due to their mechanical properties and resistance to degradation, which is why they are used in the aerospace industry. Another application of epoxy resins is in the shipbuilding industry, thanks to increased adhesion properties and resistance to water degradation. In this area, they are used as a primary construction material, a secondary application for hull shells or as a replacement for polyester composites and gelcoats. They can also be used as adhesives and sealants, varnishes, paints, but also as laminar resins for a wide range of applications.

They can be easily and quickly cured at any temperature in the range of 5 to 150 °C, depending on the type of accelerator used. One of the most advantageous properties is low shrinkage during curing, which makes it possible to minimize internal stresses. They have high adhesive strength, good chemical resistance and high electrical insulation capacity.

They differ from polyesters in the method of curing, where they are cured with a hardener instead of a catalyst. Curing can be accelerated by the application of heat, which means that the higher the temperature, the sooner the curing of the resin is achieved. In other circumstances, curing may take several hours. [7]

An overview of hardeners, their mixing ratios with epoxy resins and the curing time of epoxies can be seen in Table 3.

Table 3: Hardeners overview of company HAVEL COMPOSITES CZ s.r.o.

Resin	Mixing ratio		Pot-life
	Parts by weight	Parts by volume	100g at 20 °C [min]
133 MGS	100:35	100:40	10 - 15
135 MGS	100:35	100:40	25 - 30
136 MGS	100:35	100:40	60 - 120
500 MGS	100:40	100:50	10 - 15
H 285	100:40		50
H 505	100:27		15 - 30
			100g at 25 °C [min]
H 10	100:45	100:50	15 - 25
			100g at 25 °C [min]
C	100:60		50
L	100:40		40
			100g at 20/45 °C [min]
386 MGS	100:35	100:40	300 - 360 / 80 - 120

Table 4: Overview of epoxy resins HAVEL COMPOSITES CZ s.r.o.

Epoxy resin	List of resins
LH 145	Resin with very low viscosity and resistance to crystallization. Suitable for the production of sporting goods, boats and car parts.
LH 160	Laminating resin with low viscosity, high hardness and chemical resistance. It is used for the production of boats and boat accessories, sports equipment, models and molds. It is more prone to crystallization at low temperatures.
LH 260	It is a clear resin that is resistant to crystallization with a higher viscosity compared to LH 160. Available in three variants - with UV stabilizing substances, with a defoamer for faster removal of microbubbles and with limited flammability.
LH 289	It creates a smooth and shiny surface, and is most often used as a glaze for artificial stone. It is characterized by a lower price.
LH 288	Special epoxy resin with extremely low viscosity, which is suitable for infusion technologies. Products made with this resin are characterized by high hardness.
LH 300	Resin with higher viscosity and high heat resistance up to 150 °C. It is very important to follow the technological procedure in the production of composites.
L 20	It has good adhesion to wood, steel materials, plastics, ceramics and other similar materials.
C	Chemically very resistant epoxy resin. It is used in the construction of stops, tanks and pipelines.
L 285 MGS	High quality resin that is certified for the aerospace industry and model production. In combination with the hardener, it forms a very viscous mixture, thanks to which the fibers are supersaturated faster.

4. Evaluation of the properties of polymer resins and composites

The similarity of epoxides to vinyl esters is in the long chain molecular structure and in the reactive sites located at the end of the chain. The difference is that in epoxy resins, these sites are formed by an epoxy group instead of an ester group. As a result, they have extremely good resistance to the aquatic environment.

Compared to polyesters and vinyl esters, epoxies have very good fatigue resistance, which is also one of the many reasons why they are used in the aerospace industry. The main disadvantages include high cost, critical mixing ratios and corrosivity.

Reinforcement of matrices with different fiber content, as well as different orientation and type of reinforcement affects the mechanical properties of the resulting composite material. Therefore, it is important to pay attention to the appropriate choice of matrix and reinforcement and other additives, as well as to the selection of a suitable production technology.

Table 5: Properties of selected materials with composites

Material	Density [g/cm ³]	Young's modulus [GPa]	Tensile strength [MPa]
Steel SAE 1010 (cold processed)	7.87	207.0	365.0
Steel AISI 4340 hardened and tempered	7.87	207.0	1722.0
Aluminum alloy 6061-T6	2.70	68.9	310.0
Titanium alloy Ti-6Al-4V	4.43	110.0	1171.0
Stainless steel 17-7 PH	7.87	196.0	1619.0
High-strength epoxy matrix with carbon fibers (non-oriented)	1.55	137.8	1550.0
High-tensile epoxy matrix with carbon fibers (non-oriented)	1.63	215.0	1240.0
Epoxy matrix with E-glass (non-oriented)	1.82	39.3	965.0
Epoxy matrix with Kevlar (49%) (non-oriented)	1.38	75.8	1378.0
Epoxy matrix with carbon fibers (quasi-isotropic)	1.55	45.5	579.0
SMC pressed composite (isotropic)	1.87	15.8	164.0
Vinyl ester matrix with glass fibers (67%) (randomly oriented)	1.84	19.3	269.0
Vinyl ester matrix with glass fibers (50%) (randomly oriented)	1.80	15.8	166.0

5. Conclusion

In the production of composites, it is important to pay attention to the processing time of the resin, the so-called Gel time. Gel time is the time during which the viscosity of the resin changes, after which it is no longer possible to work with the resin or the individual layers of the resin and the reinforcement are not sufficiently connected. If this time is not observed, cavities may form after curing or the individual layers may separate from each other, resulting in reduced mechanical properties or deterioration of

the composite. Each resin has a gel time specified by the manufacturer, which can be influenced by the type of resin used or by changing the hardener used. Ambient temperature also affects the rate of transition of the resin to the gel state.

Curing at a controlled temperature changes the viscosity of the resin, which increases with increasing temperature until the resin is completely cured. By increasing the curing temperature to a certain limit, it is possible to improve the mechanical and thermal properties of composites. As the temperature rises, the curing time of the resin decreases.

The type of reinforcement used in the composite has a significant effect on the mechanical properties of the composites. Carbon composites had the highest strength-to-weight ratio compared to other composites, but their ability to absorb energy was low due to the brittleness of the material. Glass fiber reinforced composites had significantly higher energy absorption after post-curing at elevated temperatures compared to carbon composites, approximately 3.6 times. By combining the reinforcement fibers, a balance of the mechanical properties of the composite can be achieved. However, the post-curing of the already cured composite does not have such a significant impact on the mechanical properties of the composites compared to the initial curing of the composites at elevated temperature.

At the same time, however, by additional curing of the already cured composite at room temperature, the mechanical properties can be further increased to a certain temperature, regardless of the reinforcement used. The process of post-curing in the furnace at elevated temperature results in an average of 10% increase in the impact resistance of the material and a 9% increase in tensile strength, which does not represent such a significant improvement in mechanical properties as in the initial curing. Finally, it is important to note that it is necessary to examine specific types of composite materials in this way. Such an examination would determine the temperatures at which the material needs to be cured in order to fully exploit its potential and achieve maximum mechanical properties.

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Pattern steel: production technology and fracture surface evaluation

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Abstract: Presented article deals with the description of the technology of pattern steel production – forging welding, evaluation of fracture surfaces and mechanical tests of examined samples (resulting steel and its individual components). The damascus steel (pattern steel) was prepared by forge welding from a packet consist of a few hundred layers. Marbling was created by folding layers of 2 components: hard and tough steel of different thickness. For evaluation of mechanical properties was applied: Charpy impact test. The evaluation of the fracture surfaces of individual samples was performed by scanning electron microscopy (SEM). The values of mechanical properties of pattern steel themselves are in the range of values of mechanical properties of individual components. The fracture surfaces of the materials have a characteristic relief (in relation to the mechanical properties of the individual components).

Keywords: PATTERN STEEL, FORGING, LAYERS, CHARPY IMPACT TEST

1. Introduction

The term damascus steel: Damascus steel is a material with a characteristic pattern – the so-called marbling. The number of layers in the final phase is about 100-500, but there are also so-called micromaskets with thousands of layers [1]. Marbling is created by folding (combining) several layers of steel (with different carbon content / properties), joined by a blacksmith welding method. Hundreds of layers of preforms need to be translated to create a drawing. There are currently two types of damascus steel:

- genuine damascus steel – applied to tools produced in the past, the production process is not known, production by nanotechnological process is assumed (high values of mechanical properties of damascus steel were supplied by hollow carbon microfibres, coated with iron carbide fibers, production was random, not targeted) characterized by its properties – sharpness and hardness blades (used to make swords / weapons / knives),
- false damascus steel (pattern steel) – resulting from the above-mentioned interleaving of layers and joining by forging welding into patterns [2, 3].

History: Historical perspectives on production technology are due to the diverse steel designations (Damascus, Pulad, Bulat, Wootz, Crucible steel) do not match [4, 5, 6, 7]. The first written mention of Damascus steel dates back to the 3rd century AD (by the Alexandrian historian Zosimos – he gave facts about its application in India and Persia) [8]. Current studies suggest that damascus steel was produced in Central Asia and India (not Syria or the Middle East – as originally expected). The processed ingots were subsequently distributed to Middle Eastern cities, including the city of Damascus (the center of the then trade). The designation damask steel therefore does not have a clear origin (it is not based on the designation of the place), but probably from the Arabic expression damas = water (Damascus blades are often described as exhibiting a water pattern on their surface) [4, 9]. Damascus steel production technology brought to perfection by Japanese samurai sword makers in the 13th century [10, 11, 12]. The production of patterned swords gradually declined until it completely disappeared around 1750 (the cause of the cessation of production is still unknown).

Many foreign authors deal with the production of damask steels (Bulat / Wootz steels), the resulting properties and history. A group of Russian authors stands out – starting in the early 20th century. Russian metallurgists tried to renew the technology of damask steel production (technology applied in production until 1919), followed by the work of N. I. Belaiew, V. I. Basov and others [7, 13]. Scientific work also deals with testing "found" historical objects made of real damask steel [14, 15, 16]. In the case of Peterson, D. T., Baker, H. H. and Verhoeven, J. D. – the knife blade is subjected to a number of analyzes: chemical analysis using mass spectroscopy (damask steel reports low carbon content and low impurities of Mn, P, S, Si and Cu, only the elements Pb, Zn, and Au were found at the 0,01-0,05% range), analysis of microstructures, the shape and size

of grains, the tensile strength, yield strength, elongation and hardness (about 62-67 HRA) [17]. Similarly, a study [18] examining historical objects (of true damask steel) and observing the high content of cementitic nanowires, which interact with dislocations and which might have influenced the nucleation of perlite. The nanohardness as measured separately for cementite and perlite indicated striking differences in the inelastic behavior of those phases. Other groups of authors, on the other hand, are exploring the possibilities of fake damask steel production technology and its acquired mechanical properties. For example, the work of S. Fedosov – comparing several types of false damask steels after heat treatment: HRC – (numbers were received by conversion of HV) = 48-52 / KCU [J.cm⁻²] = 20.2-36 / bend angle [°] = 0-6.5 / Tensile strength [MPa] = 822-853 / Elongation [%] = 10.3-18.0 (the work also briefly evaluates the assessed fracture areas) [7]. Similar studies by Czech authors – Černý et al. describing the values of mechanical properties of damask steel samples after heat treatment (average value of Impact energy = 3.9 J.cm⁻² – tested sample in the direction of stored layers, average value of impact energy = 5.26 J.cm⁻² – tested sample in the direction perpendicular to the direction of the deposited layers, both samples after heat treatment, R_m values in the range 1169.52-1264.75 MPa) [1]. The material portal [19] states the values: yield strength = 800 MPa / HRC = 62-64 approximately (Ultra-high-carbon steel – Damascus steel). Material properties are intensive properties, that means they are independent of the amount of mass and may vary from place to place within the system at any moment. The basis of materials science involves studying the structure of materials, and relating them to their properties (mechanical, electrical etc.) [20].

2. Experimental method

Description of material: W-Nr. 1.2842 steel (hard phase) and W-Nr. 1.2705 steel (tough phase) were applied for production of pattern steel. Heat treatment of W-Nr. 1.2842 steel: detailed scheme of heat treatment describes Fig. 2 (Fig. 1 – tempering diagram), steel W-Nr. 1.2705: etching resistant, achieves hardness 44 HRC.

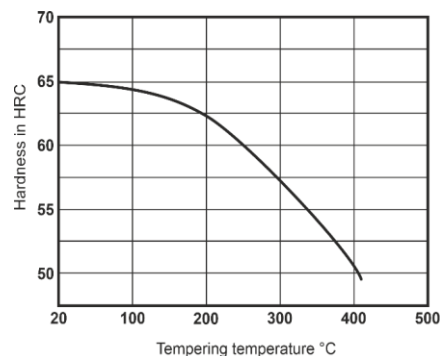


Fig. 1 Tempering diagram of W-Nr. 1.2842 [21].

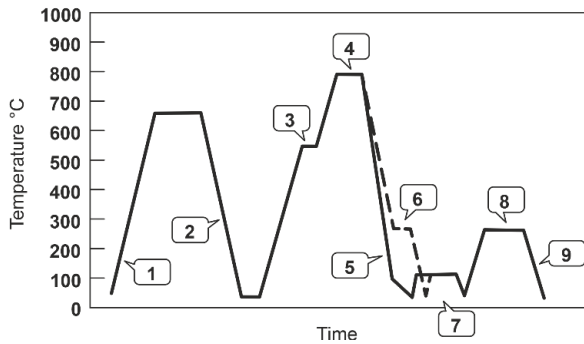


Fig. 2 W-nr. 1.2842 steel heat treatment scheme (1 – annealing to remove internal stresses, 2 – cooling in the furnace, 3 – preheating stage, 4 – hardening, 5 – oil, 6 – salt bath, 7 – cleaning / hardness test, 8 – tempering per working hardness, 9 – air cooling [21].

Pattern steel production process: the material is created by folding the selected components, the resulting number of layers: 300, the ratio of hard and tough component: 2/1. Dimensions of applied semi-finished products: 3 x 30 x 1000 mm (W-Nr. 1.2842) / 1.6 x 30 x 1000 mm (W-Nr. 1.2705).

Prior to joining, both steels and impurities were removed from the surfaces (belt grinder). They were then cut to the required length of 100 mm and cleaned with degreasing agent. The components were stacked – folded, clamped and welded, applied method: arc welding at the edges and in the middle → packet generation (principle of packet generation – Fig. 3). The package (Fig. 4) was then heated to the desired temperature (800 °C) and sprinkled with borax (eliminates oxides on the surface, helps to increase the temperature). This was followed by heating to a temperature of 1100-1200 °C and overtaking (blows – fast, even and strong enough). By repeating the mentioned procedure, a package with 100 layers (resp. 300 layers) was created, which was subsequently ground and inserted into hydrochloric acid (for visibility of marbling – interconnection of layers of tough and hard phase). When making a 300-layer packet, the layer boundary is almost unobservable in some parts. The resulting damask – see Fig. 5. Component 1 – W-Nr. 1.2842 steel is heat treatable steel (hardness and wear resistance for finish material), component 2 – W-Nr. 1.2705 steel was selected, which gives toughness to damask. Thanks to its resistance to etching the 1.2705 steel appears as the light components in the resulting structure (Fig. 5).

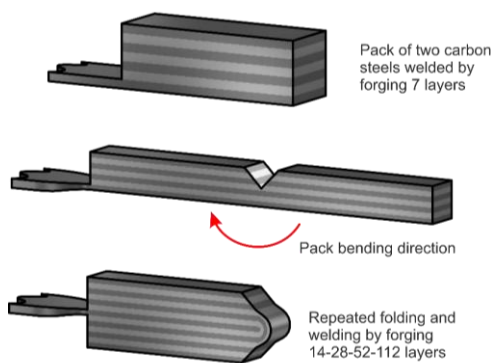


Fig. 3 The principle of pattern origin.



Fig. 4 Welded package.

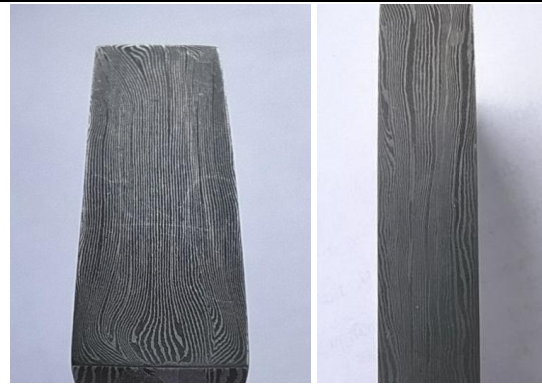


Fig. 5 The resulting material – a view in a layer line.

3. Experimental testing of steels (components and resulting material)

To observe the fracture surfaces of resulting steel (or its specific components) – samples were made with the dimensions: 10 x 10 x 55 mm (with a V-shaped notch and standardized depth). The direction of the fibers on the damask samples / the dimensions of the normalized sample are shown in Fig. 6. The test was performed on Charpy hammers in accordance with the current standard STN EN ISO 148 [22]. The principle is based on dynamic three-point bending (see Fig. 7), the body is placed on supports, and the load F acts on the side opposite the notch. hammer equals the initial potential energy W_k – according equation: ($W_k = \frac{F_G v^2}{2g}$). In the event of an impact, part of the kinetic energy is used for the deformation work of the test piece and the rest will allow the hammer to swing up to the height h ($W_p = F_G \cdot h$). The more kinetic energy is consumed to deform the body, the less the hammer deflection will be h , and thus, a higher value of material toughness → this is the difference between the potential energies of the hammer in position 1 and 2: $K = W_p - W_p = F_G \cdot (H - h)$. The measured KV values were then divided by the cross section of the test sample at the notch S_0 → thereby obtaining a notched toughness value of KCV according to the formula: $KCV = \frac{KV}{S_0}$ [J.cm⁻²]. The values captured in Tab. 1 represent average values from the total number of measurements.

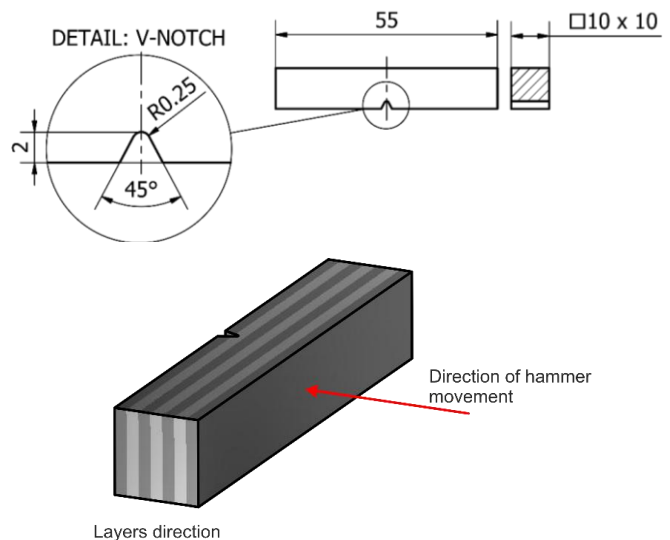


Fig. 6 Layer lines on the prepared samples (dimension of the normalized sample with V-notch) / sample for the impact bending test – placement of layers in relation to the movement of the hammer.

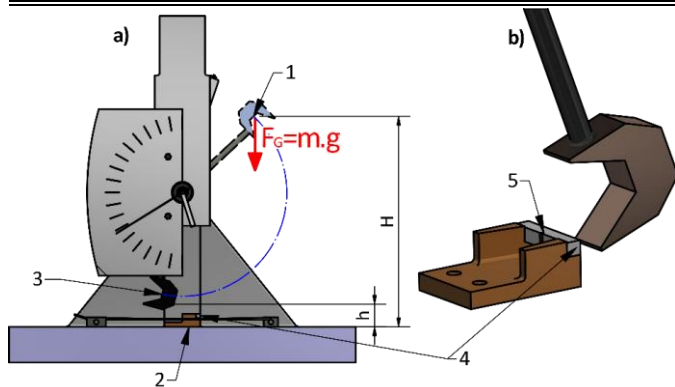


Fig. 7 Principle of the performed impact bending test (1: initial position of the hammer, 2: supports, 3: end position of the hammer, 4: test specimen, 5: notch on the body).

Table 1: Averages of measured values of notched toughness KCV (Charpy impact Test).

Material	Average value KCV [J]	Standard deviation
Component 1	3.10	0.95
Component 2	73.6	0.98
Resulting steel	13.4	0.96

Note: the toughness test was performed in a direction perpendicular to the direction of the line (deposited layers).

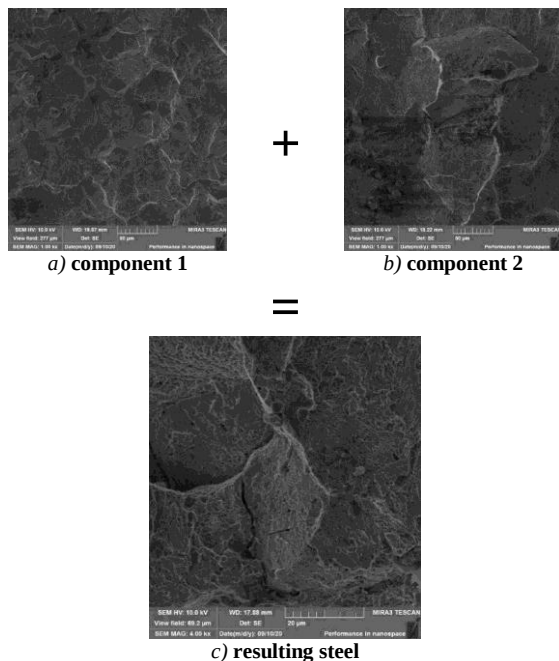


Fig. 8 View of the fracture surface of examined samples at SEM.

Figure 8 capture the fracture surfaces (types of fractures): the components of the damask (hard component / tough component) and the resulting damask itself at the set magnification of the scanning electron microscope. Component 1 shows facets of brittle – fission fracture, the energy consumed in the formation of fracture is low about 3 J (it can be stated that the fracture is low-energy – according to [23]). The images of component 2 capture the morphology of the more ductile – intercrystalline and transcrystalline fracture with a higher number of well disturbances (compared to component 1). The value of the plastic deformation energy consumed to break the sample also tells about it. The resulting damask is a combination of intercrystalline and transcrystalline damage (so-called mixed fracture surface).

3. Conclusion

The aim of the presented study is to point out the technology of production of false damask steel created by joining the layers into a whole (using the technology of welding forging). The marbling effect is created by folding hard and tough steel in a ratio of 2: 1, in relation to the different thickness of the components. The values of the consumed energy of the hard and tough component at the fracture occur correspond to the expected values. For the resulting damask, the value of energy consumed is in the range of KCV values hard versus the tough component (the conclusions of the quarry study are similar, where damask is a combination of intercrystalline and transcrystalline failure).

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Foam ceramic blocks with low thermal conductivity suitable for the construction of roads and urban square pavements and non-load-bearing partition walls

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Abstract: Lightweight porous ceramic has a number of advantages over the tightly sintered one depending on the field of application. As a building material with low thermal conductivity and good sound insulation properties, foam ceramic is a suitable material for the production of thermal and sound insulation panels, partition walls, as well as for layers laid under asphalt to protect road and urban square pavements from freezing. As a filling, foamed ceramic materials are also added during the production of lightweight concrete used in construction and architecture and in the manufacture of decorative and non-structural insulation elements. In the present study we consider the characteristics of marl clay, found around the village of Lovets near the town of Shumen, with coal as a foaming additive, and the technological regulation for the manufacture of foam ceramic blocks.

Keywords: FOAM CERAMIC, LIGHTWEIGHT CERAMIC MATERIALS, POROUS COMPOSITE MATERIALS, LIGHTWEIGHT EXPANDED CLAY.

1. Introduction

Foam ceramic materials included in various composites [1] are becoming increasingly popular in the manufacture of construction and technical elements (bricks, filters, etc.). The present study considers the possibility of using marl clay in the production of foam ceramic insulation material by foaming the latter with added coal powder [2]. For the purposes of the study, samples were developed with different weight percentages of foaming agent. The temperature dependences of the properties of the ceramic mass on the content of coal powder were studied. The chemical analysis and the phases obtained after high-temperature liquid-phase synthesis are presented and a tomographic analysis of a sample of foam ceramic material is performed.

2. Experimental part

The composition of the sample was developed on the basis of sedimentary marl rock from a deposit around the village of Lovets near the town of Shumen. The material is suitable for making ceramic products with densely sintered ceramics, as well as ones with high porosity such as insulation blocks, e.g. bricks. Since the compaction after synthesis depends on the modification of the raw material and on the temperature regime, in order to obtain foamed ceramics, to the multicomponent mass is added coal powder which releases CO₂ during combustion and acts as a foaming agent [3-4].

3.1. Research

The following studies were performed: differential thermal analysis of the modified composition (Fig. 1); chemical analysis of the clay, presented in Table. 1; X-ray phase analysis, shown in Figure 2; temperature regime in synthesis, presented in Table. 2 [5]; tomographic analysis, presented in Figures 3, 4 and 5. The ratio between closed and open pores, as well as the total porosity are shown in Table. 3, and the amount of pores with sizes from 1 to 3 mm – in Table. 4 [6].

Table 1. Chemical analysis

Chemical composition	Percentage
Na ₂ O	0,7
MgO	2,24
Al ₂ O ₃	11,36

SiO ₂	35,19
P ₂ O ₅	0,1
K ₂ O	2
CaO	19,58
TiO ₂	0,47
MnO	0,11
Fe ₂ O ₃	4,85

Based on the experiments conducted on the marl sedimentary rock, the fireclay obtained from it, as well as on kaolin and coal powder, an optimal composition for the production of ceramic thermal insulation blocks was developed. The added foaming agent constituted up to 10% of the total weight, and the high-temperature synthesis was carried out at a temperature in the range of 1,115-1,120° C. Obtained as a result was a lightweight foam ceramic material, with a low coefficient of heat conduction in the range of 0.095 to 0.12 W/m²K, compressive strength of 120 to 130 MPa, and wear resistance of 0.75 g/cm².

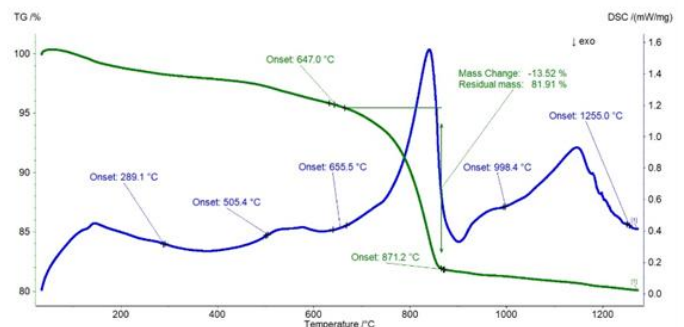


Fig. 1. Differential thermal analysis of a modified composition based on marl sedimentary rock with the addition of 10% coal dust.

A loss of mass of 13.52% is observed following the ignition of the composition's mass modified with the foaming agent (Fig. 1). Mass losses are due to the processes of dehydration, decarbonization and oxidation of the carbon from the coal dust. There is a change in the thermogram at different temperatures, with the above mentioned processes starting as early as at 290° C. An endothermic effect is observed in the temperature range from 800 to 900°C, associated with the decomposition of the carbonates. Liquid-

phase transition at a temperature of 1,150° C is observed, and complete melting at a temperature of 1,255° C, which means that the sintering must take place before the maximum temperature is reached. X-ray phase analysis of the obtained foam-ceramic material has also been performed showing the presence of the petrugical phases diopside and anortite.

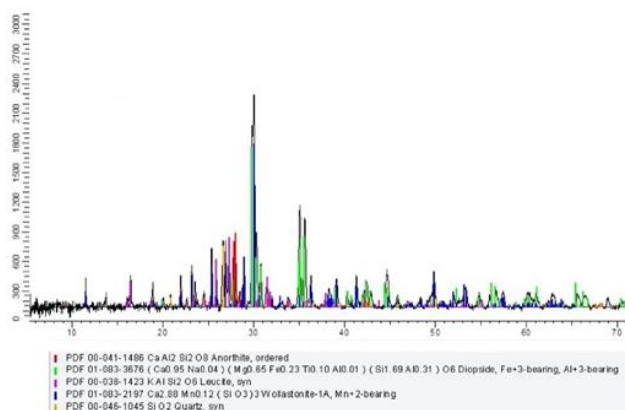


Fig. 2. XRD of the modified marl clay.

The temperature regime of the synthesized sample is presented in Table 2. Heating is done gradually, raising the temperature by 2°C / min. The retention of the temperature is in several intervals - the first one allows to separate the freely bound water, the second one helps to dehydrate the structural water, the third one allows to complete the decarbonization processes, and finally the liquid-phase transition takes place.

Table 2. Temperature regime in the synthesis of the studied materials.

Temperature, °C	Retention, min
150	60
650	60
950	180
1120	180

The computer tomography method was used to obtain information about the volume of the material, as well as to calculate the porosity. After irradiation using 3D X-ray microtomographer SkyScan 1272, a reconstruction of the sample was performed using NRecon software, where the obtained X-ray projections were “assembled” to produce a digital model of the sample. Using CTBox software, 3D images of the sample and images of its different sections can be obtained. The software for calculating various geometric parameters is CTAn, which in our case yielded data on the closed and the open pores, on the total porosity, on pore diameters and on the pore percentage distribution in the sample volume. Figure 4 shows visualizations of the sample, which is irregularly shaped, has dimensions of approximately 35 x 20 x 5 mm, and is rotated around a vertical axis. Clearly visible are the open pores formed in the synthesized sample. Airspaces of different sizes and shapes are observed, passing through the whole volume of the sample.

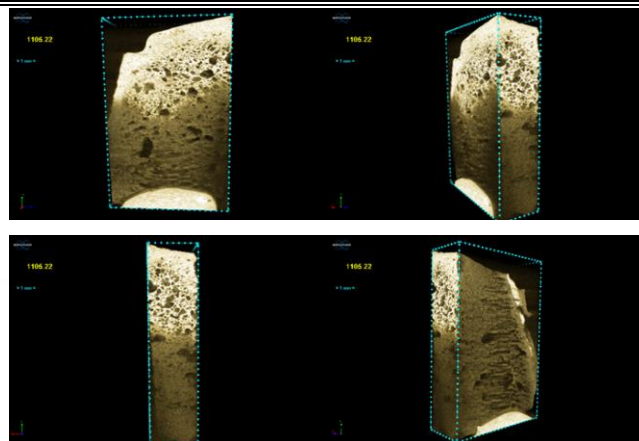


Fig. 3. Visualization of the sample rotated around a vertical axis.

Fig. 3 shows a longitudinal section of the scanned sample in 1 mm steps. Deeper inside can be observed the formation of new air spaces in the individual layers.

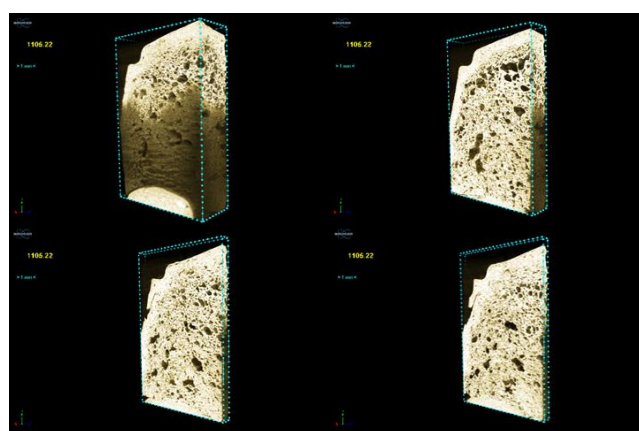


Fig. 4. Visualization of the longitudinal section of the sample in steps of 1 mm.

Fig. 4 shows a cross section in steps of 1 mm. The formation of larger open pores below the surface layer is observed, which indicates that the surface layer is significantly denser. This might facilitate the process of forming products with a relatively smooth and dense surface and a porous structure.

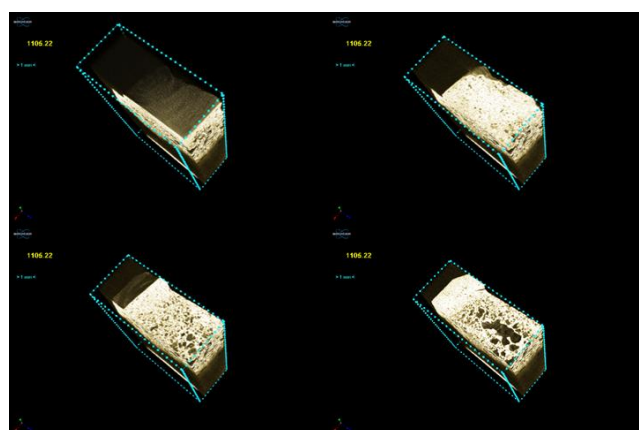


Fig. 5. Visualization of the cross-section of the sample in steps of 1 mm.

A total of 1374 layers of the scanned sample were examined at an image resolution of 1224 x 980 pxl, with a pixel size of 21.57 µm, at a rotation step of 0.6° and full rotation of the sample (360°). The filter used was 0.11mm Cu at source voltage and current respectively 100 kV and 100 µA. The percentage of closed and open pores, as well as the total porosity, are presented in Table 3. In

Table 4 is shown the percentage of pores with dimensions from 1 to 3 mm relative to the total amount.

Table 3. Ratio between closed and open pores, as well as total porosity of the studied sample.

Pores type	Percentage
Closed pores	2.47
Open pores	26.41
Total porosity	28.88

Table 4. Percentage of pores with sizes from 1 to 3 mm.

Pore size	%
under 1 mm	83.65
from 1 to 2 mm	14.50
from 2 to 3 mm	1.85

3. Conclusion

A foam-ceramic thermal insulation material has been created that can be used for the making of products with improved physical-mechanical and tribological indicators, with a low coefficient of heat conduction, and suitable for application in the road and civil construction industry.

Acknowledgement

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