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CAST EQUIPMENT FOR HEAT TREATMENT FURNACES

ЛИТЕЙНОЕ ОБОРУДОВАНИЕ ТЕРМИЧЕСКИХ ПЕЧЕЙ

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Abstract: Various designs of equipment used in heat treatment furnaces are presented. The equipment is assembled from components varying in shape and size. In this case study it is composed of castings only. Castings are made from creep-resistant alloys, mainly cast austenitic steel and nickel alloys, using gravity poured sand molds. The design should allow for the simultaneous solidification of all thin-walled cast parts. The study focuses on the equipment for the heat treatment of parts of uncommon shape and size, or parts that require special heat treatment conditions. It is used for the charge formation in furnace and transport of this charge inside and outside the furnace. Different designs are illustrated. Their shape and size depends on the type of furnace, production volume, and the number and shape of heat-treated parts.

KEYWORDS: CASTINGS FOR HEAT TREATMENT PLANTS, TECHNOLOGICAL EQUIPMENT, GRATES, BASKETS

1. Introduction

A part of tooling in most heat treatment furnaces is the technological equipment used for the formation of charge and its transport inside and outside the furnace. The performance life of this equipment often determines the reliability and durability of the furnace [1–3]. There are three procedures commonly adopted in the design of this equipment, each of them depending on the type of furnace, production volume, and the number and shape of heat-treated products. Future user of the equipment must decide on the choice of one of the following solutions [3]:

1. Use standard furnace equipment provided by the manufacturer, and then, depending on current production needs, add to this equipment, within his own capacity, other complementary elements for handling of the heat treated parts.
2. Use in standard furnace the equipment of his own non-standard design.
3. Order at a manufacturer a nonstandard furnace and install in this furnace the pre-designed equipment of nonstandard shape and size.

This study describes a user-tailored type of technological equipment, designed for the heat treatment of selected parts of machinery in a furnace of uncommon design. The need to take a "special approach" to the design of the equipment was dictated by:

- the shape and size of heat-treated parts,
- the need to increase the durability of the equipment,
- specific heat treatment parameters,
- other requirements essential for the required quality of heat-treated parts and reduced cost of their production.

The presented equipment has been made from cast components only, using creep-resistant alloys, mainly cast austenitic chromium-nickel / nickel-chromium steel and nickel alloys [3–5].

2. Design of the equipment

In designing of the equipment, the engineer is guided by the following principles [1, 3, 6–9]:

1. As far as possible, both the equipment and the heat treated parts should form a compact whole.
2. The mate components of the equipment should be joined together in a loose way. Loose fit allows free heat distortion of connected components in the range of operating temperatures. It also makes the replacement of worn out parts much easier.
3. Different components of the equipment should have the same wall thickness and the walls should be as thin as possible. It is recommended to avoid heavy build up of material separated by thin walls from other components.

The equipment shown in Figures 1–10 has been designed in accordance with the requirements formulated earlier. The individual components are connected with pins.

The equipment for the heat treatment of shafts of a wind turbine (Fig. 1) is designed for use in a pit furnace. The heat-treated batch consists of three shafts, each weighing 920 kg (Fig. 1a). The weight of the equipment alone is 1280 kg and the whole is composed of 72 pieces (Fig. 1b).

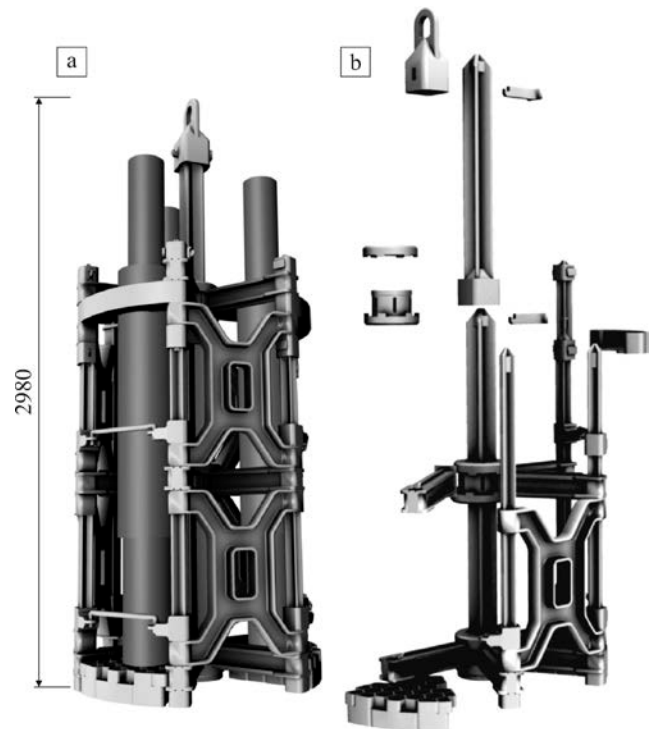


Fig. 1. The equipment for the heat treatment of shafts of a wind turbine: a) general view [3, 9], b) single components

The equipment shown in Figure 2 is used for the heat treatment of turbojet engine gas guide vanes. The process of heat treatment is the last one in the refurbishment cycle of these vanes. The user request was to set the guide vanes in a vertical position in the equipment using base elements, for which the additional design was made (Fig. 2a). However, with this setting of the treated parts, any change in the equipment position during transport would have to be done with utmost care, since the gravity center of heat-treated parts would be located at a considerable height. Changing the setting of heat-treated parts (Fig. 2b) eliminated this inconvenience, bringing additionally a number of other advantages, to mention as an example the loading capacity of the equipment increased from 18 to 20 parts, the overall weight of the equipment reduced by 150 kg, and the manufacturing cost reduced by 12%. Then the total weight of the equipment (Fig. 2b) was 414 kg, and it consisted of 42 items, this including 29 pins.

The equipment for the heat treatment of turbojet engine rotor blades (Fig. 3) is a good example of how the conversion from a welded structure to a structure composed entirely of castings can increase the life of the elements [3, 10].

This equipment is to be used in a hood furnace. The weight of the modified structure (Fig. 3a) is 280 kg. The equipment is composed of 261 parts (Fig. 3b), of which 192 are hooks for hanging the individual heat-treated blades (Fig. 3a).

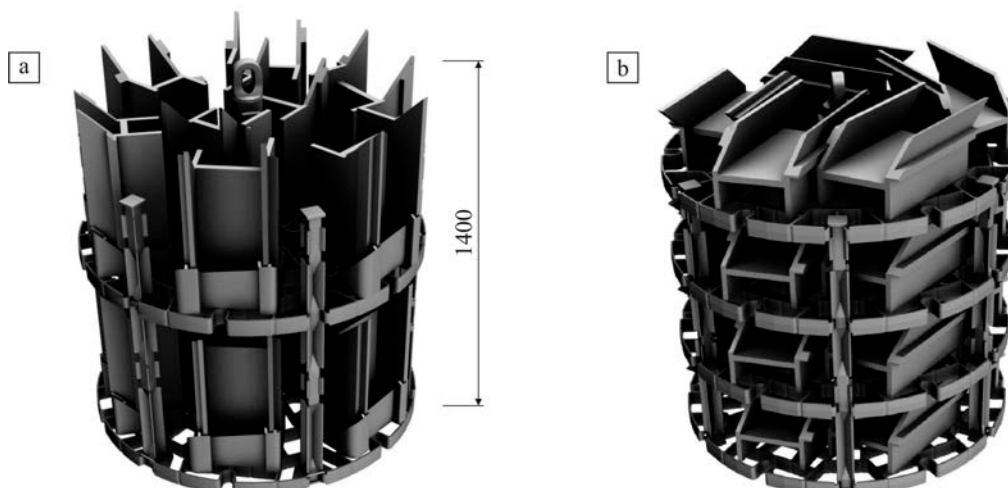


Fig. 2. The equipment for the heat treatment of turbojet engine gas guide vanes [9]: a) initial design, b) modified design

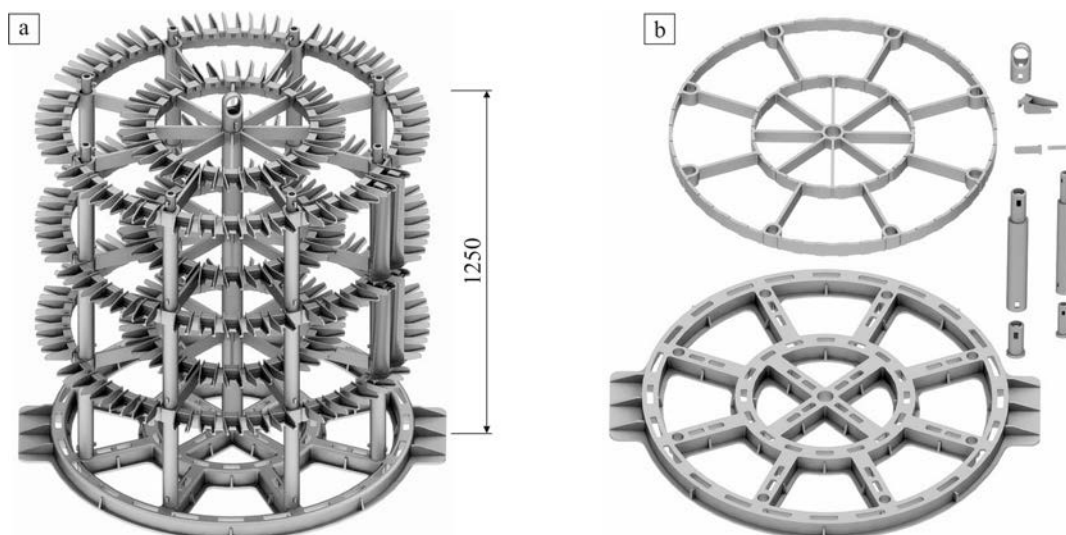


Fig. 3. The equipment for the heat treatment of turbojet engine rotor blades [3, 9]: a) general view, b) single components

In the next step of the modification of the equipment design (Fig. 3a), also the hook, on which the blades are hung, was modified (Fig. 4). This change significantly increased the number of blades heat treated in a single cycle.

The equipment shown in Figure 5 was designed for the heat treatment of tension springs for railway electric traction. It was to be used in the pusher furnace. The design of the equipment shown in Figure 5 was tailored to the user specific needs; hooks were introduced to facilitate transport outside the furnace.



Fig. 4. Increased capacity of the equipment shown in Fig. 3a by the use of double hook [9]

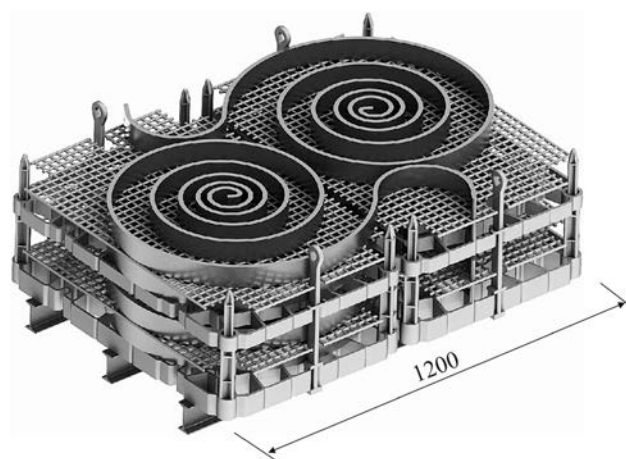


Fig. 5. The equipment for heat treatment of springs [9]

Baskets are commonly used in the heat treatment process, especially when the process of annealing is done on small parts. The use of baskets allows maximum utilization of the furnace working space and facilitates work organization. The equipment shown in Figures 6 and 8 has been designed with a view to encouraging the users of baskets welded from the wrought semi-products to switch over to the use of baskets made of cast components.

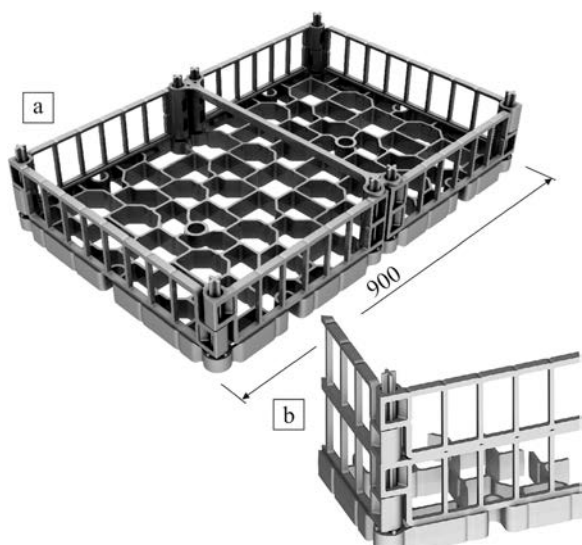


Fig. 6. Basket: a) general view, b) high capacity design with additional side walls [9]

Basket (Fig. 6a) is a sort of container designed for the heat treatment of small parts in the chamber furnace. Parts are placed in a basket in bulk. Long columns allow increasing the loading capacity of the basket, since a number of extra side walls can be added (Fig. 6b).

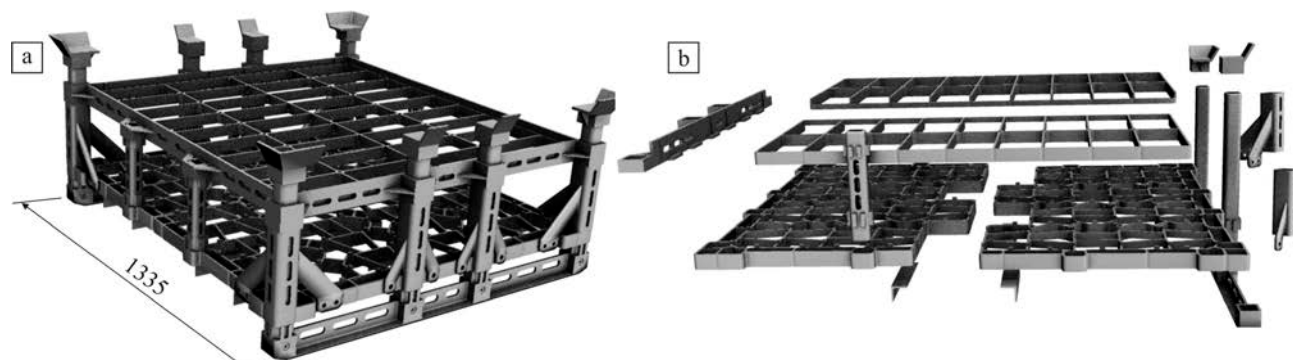


Fig. 8. Modified design of basket shown in Figure 7 [3, 9]: a) general view, b) single components

Welded baskets (Fig. 7) for annealing of the cast gearbox bodies are used in the roller pusher furnace. The one shown in the drawing has been replaced with a basket made of cast components (Fig. 8a). The basket has a weight of 440 kg and consists of 32 castings.

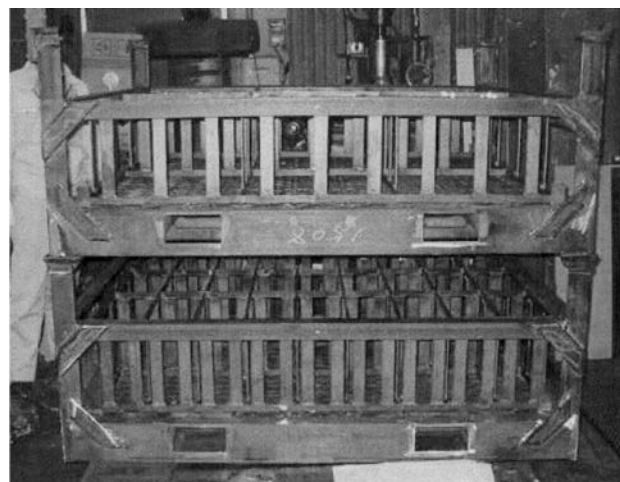


Fig. 7. Welded basket for annealing of gearbox bodies [3, 10]; the gearbox bodies are placed in separate compartments of the basket

Some fragments (or the entire surface) of the ceramic lining of the furnace for heat treatment may require shielding or other means of protection to prevent them from getting damaged during operation.

The equipment shown in Figure 9 illustrates the method of protecting the ceramic hearth of a bogie hearth furnace from mechanical damage during loading / unloading of charge.

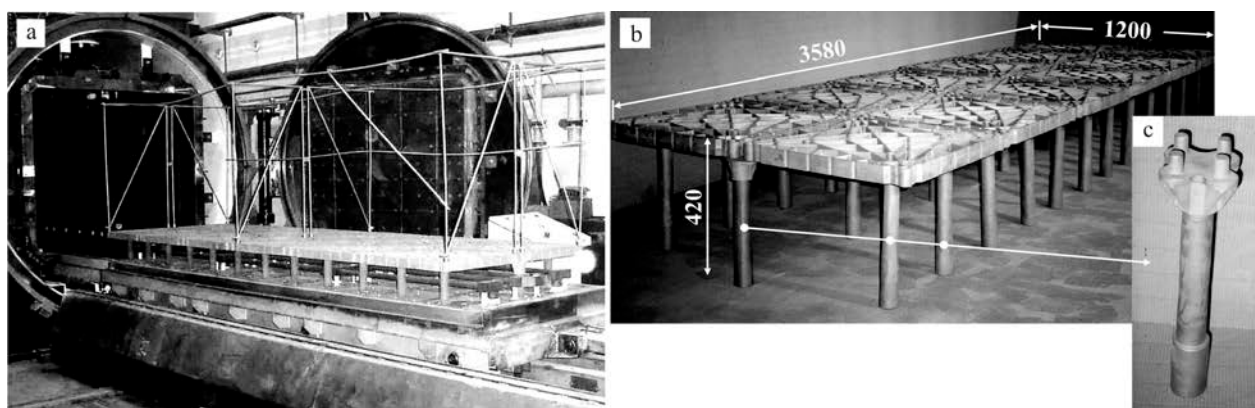


Fig. 9. Vacuum bogie hearth furnace for annealing of metal powders [3, 9]: a) general view; construction welded from steel rods set on a stem indicates the space occupied by the containers in which the charge is placed, b) the core made from pallets and racks set on the furnace hearth

The hearth of the furnace is provided with an electrical heating system arranged on a ceramic substrate (Fig. 9a). The equipment, in addition to protecting the hearth of the furnace, has also another task, namely that of maintaining a stable position of the heavy charge above the heaters without constituting a significant barrier to heat flow in this area. To ensure that these requirements are met, a base was designed that consists of 12 openwork pallets and 30 columns (Fig. 9b, c). The columns with heads ending in bolts (Fig. 9c) join pallets together. Loose connection of these elements enables them (and the equipment) to undergo free heat distortion in the range of operating temperatures.

In the process of hardening products made of titanium alloys it is necessary to cool them very rapidly in a cooling liquid. Additionally, the heat treatment process is difficult to carry out if products are heavy and intricate. The equipment for the heat treatment of parts made from titanium alloys is shown in Figure 10.

The equipment (Fig. 10) is designed for the heat treatment of parts of the aircraft chassis. It consists of 55 components with a total weight of 450 kg. The main components of the equipment are: a body with a transport hook, a latch (Fig. 10–1, 2) and a sling (Fig. 10–3). The charge of up to 2500 kg is hung on sling hooks (Fig. 10–4). The equipment with the charge is suspended under a crane and introduced into the furnace chamber. In the furnace it is held at a predetermined temperature for a predetermined lapse of time. Then, together with the furnace, it is placed above the liquid coolant reservoir and lowered into the reservoir under its own weight.

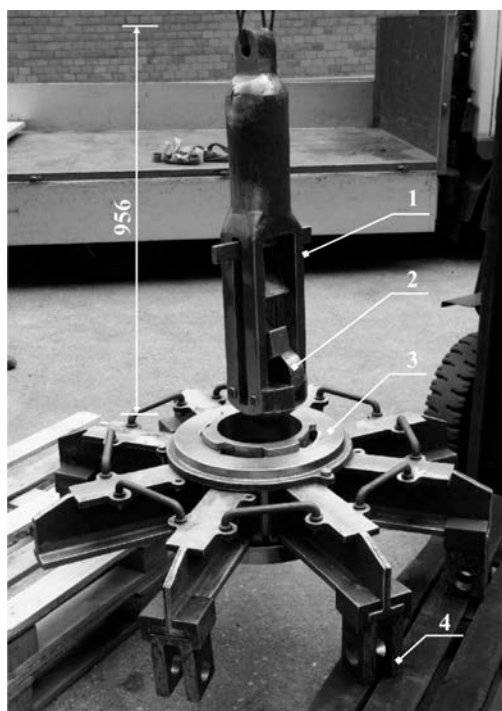


Fig. 10. The equipment for the heat treatment of parts of the aircraft chassis [3]: 1 – body with transport hook, 2 – latch, 3 – sling, 4 – clip for fastening of heat treated parts

3. Final remarks

When the described components of the technological equipment were designed, three groups of factors that determine the reliability and durability of this type of construction were examined [3]. These factors include:

1. Construction – operating conditions (temperature changing in a wide range of the operating values) and the expected parameters of the heat-treated charge (size, shape, weight).
2. Material – chemical and phase composition, as well as the morphology of microstructure providing the required creep properties during operation.
3. Casting – the use of technological solutions in the manufacture of castings, which guarantee low level or complete elimination of defects, both external and internal.

When decisions are made jointly by the manufacturer and foundry process engineer as to the selected material, design and technology, it should be remembered that the results of the operation of these three factors overlap and together affect the life and stability of the equipment considered as one integral whole.

All variants of the equipment shown in Figures 1–9 were designed by the authors of this study. Most of the types have already been used in industrial practice, in whole or in part. In the case of the equipment shown in Figure 10, the authors participated in the process of its manufacture. All designs are protected by intellectual property laws.

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SOME OPTIMIZATION METHODS FOR INCREASING THE ENERGY EFFICIENCY OF THE WATER SUPPLY SYSTEMS

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Abstract: We are witnessing the rapid growth of the energy prices and there are expectations that they will continue to grow in the future. Consequently, there is a constant need of energy efficiency improvements that could be achieved by decreasing of energy losses, smart and efficient energy utilization and conservation of energy resources.

The water supply systems are large energy consumers. So, the investments in the increasing of their energy efficiency will not only have an economic dimension, but also they could have large positive effect on the environment protection. In this paper, an analysis of the degree of efficient usage of the energy and the appropriate techno-economic analysis of the energy consumption for a real water supply system is presented. Few methods for increasing the energy efficiency of water supply pump stations and an analysis of the potential benefits of this method are proposed and discussed too.

Keywords: WATER SUPPLY, ENERGY EFFICIENCY, OPTIMIZATION, ECONOMY

1. Introduction

The water supply systems consume electric power at each of the stages of the water production and supply chain: starting from pumping the water to the water treatment plant, along the water treatment process and during distribution of the water via the water supply network.

Energy losses in these systems are generally conditioned by a several reasons: inefficient pump stations, poor system design, installation and/or maintenance, old pipes with high network losses, bottlenecks in the supply network as well as inefficient operation strategies of the various supply facilities [1].

This paper proposes a few measures for increasing the energy efficiency of a typical water supply system, and a further analysis of a possible technical and economic benefits of these measures are defined. Several appropriate proposals for the modernization of this water supply system are given, with application of some contemporary computer techniques and procedures.

2. Analysis of a Typical Water Supply System

The investigated water supply system is the water supply system of the Municipality of Radovich, which operates through mixed gravitation/pumping mode, where gravitational system is used from three existing water catchments: "Ambari", "Stara Kaptaza" and "Filter Stanica", on one side, and water pumping system from the two pumping systems: "Industrija" and "Raklish", on the other side. Both pumping systems are connected with drawn pool which is filled with water from ten existing water wells [2].

The amount of water consumption is a time-variable function with the amounts that significantly varies annually, monthly, daily and even hourly. These variations are generally implied from climate condition changes, the work of the major industrial plants, the number of inhabitants, the standard of the population, etc. However, usually there is larger water consumption during the summer period compared to the winter period [3].

The average daily water consumption during winter was 89 l/s, while in the summer the water consumption goes as high as 122 l/s [2]. This difference indicates a possibility of introducing two separate operational modes for the water supply system, the summer operational mode and the winter operational mode. This was the firstly suggested activity among the others for increasing the energy efficiency of the whole water supply system [2].

In order to analyze the characteristics of the water supply system of the Municipality of Radovich, a real simulation of the system was made using the LabView simulation package.

3. Annual Electricity Consumption

To determine the measures for energy efficiency improvement of the system, the analysis of the electricity costs for the last 6 years was done. The results of this analysis are shown on Fig. 1.

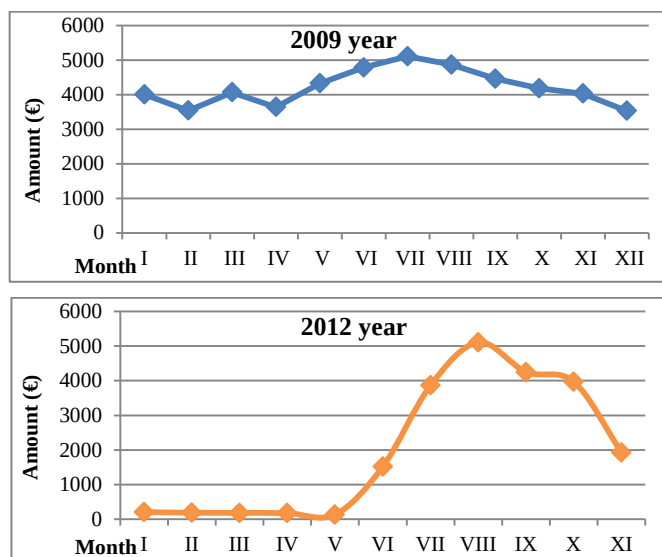


Fig. 1 Cost paid for electricity consumption for 2009 and 2012 year

It can be noticed that in 2009 the company had large electricity cost consistently all year around. Surging water consumption during the summer months is the main reason for larger cost in this period of the year. In 2012, the company significantly reduced electricity cost, mostly as a result of disconnection of the pumping stations during the winter i.e. the introduction of only the gravitational mode at the end of 2010 during the winter period.

Additionally, an analysis of the cost for the consumed reactive power for the period between 2008 and 2013 was made. The results are shown in Fig. 2, where it can be seen that in those 6 years the company had really high cost for consumed reactive power.

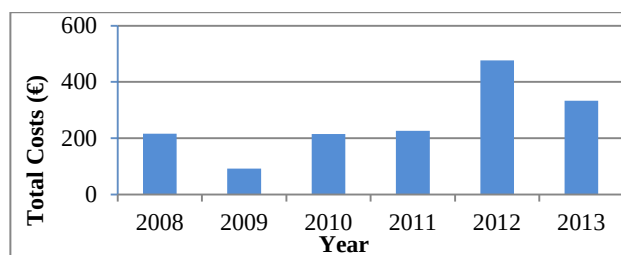


Fig. 2 Reactive power cost paid for the period between 2008 and 2013.

4. Problems and Weaknesses in the Water Supply System

From the analysis of the current state of the system and the reference annual consumption we realized that by the end of 2010, successful effort for increasing the energy efficiency in the system was made i.e. the introduction of the zonal water supply brought significant economic benefits for the company.

Additionally, from the analysis of the reactive power consumption we realized that this typical water supply system is using two types of electric motors which use excessive reactive power directly from the power grid, i.e. they have low power factor. This, so-called **reactive power** used by some power devices for creating an electromagnetic energy as a medium for conversion of the energy from one to another form, is not converted into useful work [4], therefore brings only additional energy cost to the company.

From the analysis of the pumps operation mode of the pump station "Industrija", we realized that except the turning off mode for the winter months, there is no other way to regulate its work during the summer months. According to received information, turning on and off is performed manually by the operator. This was considered as another subjective reason for increased electricity cost.

5. Research Results

During the research, beside reorganization of pump operation for winter and summer regimes, a set of additional measures to overcome the perceived weaknesses in the system were investigated and proposed, among which the most significant were the following two measures:

- the improvement of the power factor of the pumping systems, i.e. decrease the amount of reactive power taken from the grid and replace it with locally generated one, and
- the development of a system for automatic regulation of the three main parameters in the water supply system: pressure, water flow and the amount of water in the reservoir.

5.1. Measure #1: Reorganization of the Pumps Operation

This measure provided electricity cost reduction and some technical benefits:

- Reduced work of the motors and pumps,
- Increased motors and pumps efficiency,
- Extended "working life",

The main disadvantages of this measure were low water supply quality or reduced pressure and water flow during the summer months, and consistently the same cost for water supply services for that period of the year. Because there were no additional investments for this measure and there was saving of around 67.5%, we could conclude that this measure was a highly cost-effective measure.

5.2. Measure #2: Reactive Power Compensation

With the application of adequate reactive power compensation generated locally by installed capacitor banks, additional increase of the energy efficiency of the whole system could be expected. In such case, the installed capacitor banks could provide only a part of the requested reactive power, leading to a reasonable increased value of the power factor at least to a level of 0.96. This is because only a power system that have power factor less than 0.95 are required to pay additional cost for taking the excessive reactive power from the electric power grid [5].

Calculation of the required reactive energy for compensation and selection of the type of compensation are two most important steps to achieve optimal cost-benefit of the proposed activity.

The amount of added reactive power could be calculated using well-known formula:

$$Q_c = Q_1 - Q_2 = P * (\tan\phi_1 - \tan\phi_2) \quad [\text{VAr}]$$

Based on the analyzed data, we made a calculation of the required reactive power used by both types of motors which are used in this particular water supply system. Thus, the calculated amount of reactive power that should be additionally provided by the capacitor banks was 4.9 [kVAr], and 12.9 [kVAr] for each type of the electric motor, respectively. Therefore, to achieved a full reactive power compensation for the whole electricity supply system (both pumping stations and all five motors) to the desired value for the power factor $\cos\phi=0.96$, a total amount of 40.5 [kVAr] reactive power was required [6].

Because of the power supply stability and continuous load factor, as well as the short distance between the pumping stations and the supplying transformer substation (*less than 10 meters*), the central compensation system was proposed. The capacitor banks should be installed at the same bus bar as the pumping stations next to the power transformer, to provide enough reactive power for the whole installation. Using the layout shown in Fig. 3, one could eliminate tariff penalties for excessive consumption of reactive power from the grid on one side, and on the other, relieve the supply transformer from unnecessary reactive load, increase its efficiency and prolong its operational life [4].

The main disadvantage of this central compensation mode is the fact that the reactive current generated by the capacitor banks would still flow through the supply cables towards the pumping stations, generating additional power losses. However, due to the very short distance between the power transformer and the pumping stations, increase of the power losses should be insignificant [6].

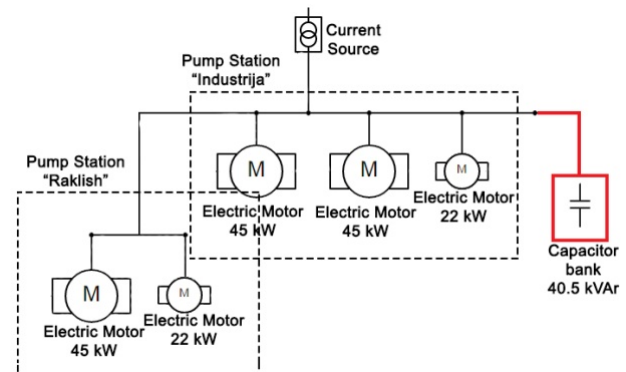


Fig. 3 The pump stations with central reactive power compensation system [6]

Speaking about the economic benefits of this measure, the total financial resources spent for procurement of the reactive power for the period between 2008 and 2013, (Fig. 2), were estimates at 1,559€, i.e. an average of 259.83€ per year, while the total investment for purchase and installation of the proposed compensation equipment and the realization of this improvement method was estimated at 326.5€. This investment could be also estimated as a cost-effective measure because the full investment in this kind of capacitor banks would be paid off for approximately 1 year and 3 months. To be precise, one could conclude that only with the implementation of the proposed measure this company could decrease the existing operational electricity cost for at least 1.7%.

5.3. Measure #3: Pumping System Operating Mode Optimization of the Depending on the Needs and Electricity Prices

The pumping system operating mode is a very complex process for large water supply systems. In our research the various operation modes of pumping system were investigated in order to find the one that will provide reduced power consumption and reduced cost for pump station maintenance. The increased electricity consumption during the months from May to November shows that it is necessary to activate both pumping stations.

To determine the electricity savings which can be achieved with the implementation of this measure, the real simulation of the system using the LabView simulation package was made. For this purpose, the data for the maximum hourly water consumption for the different parts of the city had to be known and used in the process simulation. For simulation purposes, the parts of the city which are water supplied using the pump station "Industrija" were only considered. Fig. 5 shows a graph with the values for the maximum hourly water consumption connected with this pump station.

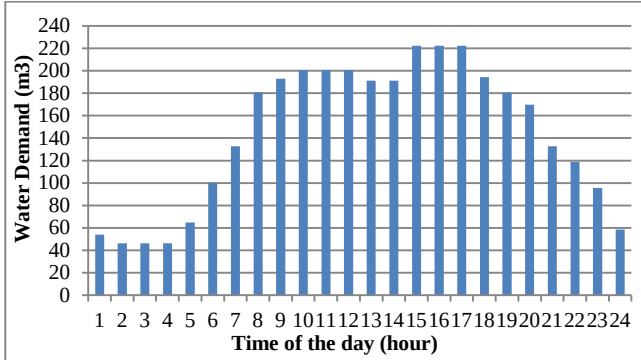


Fig. 4 Maximum hourly water consumption

Amount of Water Regulation

With the regulation of the amount of water in the reservoir, the costs optimization can be achieved only in respect of the company. The first step of the implementation of the proposed measure was to put into service the reservoir "Industrija". The optimization was achieved by determining the optimum upper and lower level of the water in the reservoir. Initially 900 m³ for upper amount of water was considered i.e. the maximum capacity of the tank. Filling the reservoir to the maximum level through the night was planned.

The simulation is run for two periods: day-time and night-time.

- the period between 7:00 and 22:00, or the period of high tariff and accordingly, the high electricity prices, and
- the period between 22:00 and 7:00, or period of low tariff and accordingly, the low electricity prices.

Tab. 1 shows the results of the simulation when only one parameter is regulated (amount of water in the reservoir), i.e. the target function are total amount of money which the company would spend if the proposed measure is realized.

Table 1: Costs of various optimization parameters

Hysteresis		7:00 h – 22:00 h		
		200 m³ & 300 m³	200 m³ & 500 m³	200 m³ & 900 m³
7:00 h – 22:00 h	800 m³ & 900 m³	37.74 €	38.33 €	44.24 €
	500 m³ & 900 m³	41.45 €	39.90 €	47.32 €
	300 m³ & 900 m³	41.58 €	41.51 €	47.53 €

From the table can be seen that there is the lowest electricity consumption when the values of the upper and the lower level of the water during the period between 07:00 and 22:00, would be 200 m³ and 300 m³, and while for the period from 22:00 to 07:00 would be 800 m³ and 900 m³.

Water Pressure Regulation

The second set of optimization methods which use the same cost function - minimization of the company costs, is realized with the introduction of one additional optimization criteria: the amount of the water pressure in the water supply system. In this case, we

"maintain" the pressure for the whole operational time to optimal value for water pressure in the water supply systems, at the value of 5 bar, without considering the amount of water in the reservoir. In this case, the optimal solution for 24 hour operation gives the following optimal values: consumption of 720 kWh during the high tariff period and 241 kWh during the low tariff period, or 44.24€ for whole operational period of 24 hours, or monthly (30 days period), the company could spend approximately 1327.32€ for pumping purposes.

Amount of Water and Water Pressure Regulation

Finally, optimization was realized using both optimization criteria jointly: (i) the amount of water in the reservoir, and (ii) the value of the water pressure in the water distribution system. The same optimization target function – the minimization of the energy cost was used. In this case, besides providing reduction of the operational cost for the water supply company, the obtained optimized operational mode results with rising of the quality of the water supply services for all customers connected to the system, mostly due to ensured minimum water pressure in the distribution network as requested by the water supply standards.

The optimization results for this two-parameter optimization procedure shows that for 24 hour operation the company will spend 685 kWh during the high tariff period (day-time) and 244 kWh during the low tariff period (night-time), or a total of 42.50€ per day, or monthly cost could be estimated at the amount of 1275.12€.

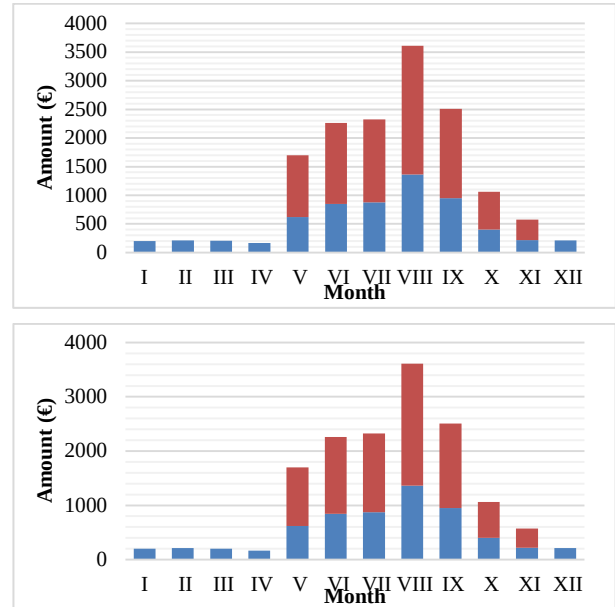


Fig. 5 Monthly savings with optimization of the amount of water in the reservoir (above), and monthly savings with optimization of the amount of water in the reservoir and the water pressure (below)

According to the simulations one could come to the conclusion that the largest energy savings could be obtained when the pumping station "Industrija" works in the optimization mode only for the amount of water in its reservoir. The savings per month that would be obtained with the implementation of this measure are given in Fig. 5, graph above. The amounts of money that the company will save only by the implementation of this measure are shown with red color on the above graph on Fig. 5. The results show that with usage of this optimization mode only, the company annually could save approximately 9 275€.

However, this optimization mode does not provide the improvement of the water quality supply services, i.e. sometimes, especially during the summer months the users are "receiving" the water with extremely low pressure (below 5 bar). Therefore, the optimization mode must include the quality of water supply services, i.e. one should definitely include the second optimization parameter, the value of the water pressure at the point of the last consumer in the water distribution system. This solution could be

optimal not only for the water supply company but also for all customers connected with this water supply system. The savings per month in such optimization mode, are presented in Fig. 5, graph below. The results show that with usage of this optimization mode only, the company annually could save approximately 8 681€.

This optimization mode could not be achieved without implementation of appropriate SCADA system for on-line monitoring and control of the whole water supply system. As part of our research, the investment cost for purchase and installation of such SCADA system was also analyzed. The investment cost according to the regional prices for purchasing and installation of middle range SCADA system was estimated at about 21 700€.

Having into account the cost for additional SCADA investment and the annual savings that the company could achieve by implementation and utilization of that SCADA system, one could calculate that the pay-back period in the first case of the optimization (only the water level in the reservoir) could be approximately 2.3 years. In the second case of the optimization (water level and water pressure combined) the expected pay-back period could slightly increase, but even in that case it could be around 2.5 years. Both pay-back periods are acceptable and show very high cost effective measures that could be quickly and efficiently implemented in such water supply systems.

6. Conclusion

According to the aforementioned results, the type and the essence of the proposed measures for operational cost reductions and energy efficiency improvements, in Table 2 the economic benefits of each of the proposed measures are summarized:

Table 2: Investment value and repayment time of the proposed measures

Proposed Measures	Investment value	Repayment time
Reorganization of the Pumps Operation	/	/
Reactive Power Compensation	326.5 €	1 year & 3 months
Pumping System Operating Mode Optimization	21 700 €	2 years & 4 months or 2 years & 6 months

According to the summarized results shown in Tab. 2, for this typical water supply system, we suggest:

- 1) Further improvements of zone-based water supplying method in order to improve the quality and the quantity of the water supply services.
- 2) Procurement and installation of adequate equipment for reactive power compensation for elimination of the unnecessary financial costs due to excessive reactive power consumption.
- 3) Activation of "Industrija" water reservoir for optimization of the water supply mode for the whole city.
- 4) Investment in the adequate SCADA system for monitoring and management of the water supply system, especially for the amount in the water level in the reservoir, optimization of the pumps operating mode with the respect of the water needs and electricity prices.

This ranking list of measures is proposed to the responsible persons in the company in order to decide which of the proposed measures are technically and economically viable for implementation by the company.

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RELIABILITY IMPROVEMENT PROBLEM OF INSTRUMENTATION AND CONTROL SYSTEMS SOFTWARE

ЗАДАЧА ПОВЫШЕНИЯ НАДЕЖНОСТИ ПРОГРАММНОГО ОБЕСПЕЧЕНИЯ СИСТЕМ УПРАВЛЕНИЯ ТЕХНОЛОГИЧЕСКИМИ ПРОЦЕССАМИ

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Abstract: *The problem of increasing reliability of multi-version software of modern control systems for industrial automation was reduced to a problem of pseudo-Boolean optimization problem of knapsack type. For solving this problem, various methods were suggested.*

KEYWORDS: CONTROL SYSTEMS, MULTI-VERSION SOFTWARE, PSEUDO-BOOLEAN OPTIMIZATION

1. Introduction

Modern instrumentation and control systems include tens and hundreds of complex hardware, software and firmware components such as sensors, executive elements, communication channels, information processing systems and software modules. Crucial units are equipped with duplicated sensors, actuators, telecommunication channels, servers for information storage and processing, client terminals. Producers of industrial automatic equipment have extensive statistical information on refusals for each type of devices [8]. Having such information, the designer can estimate risks of refusal of each subsystem and design crucial components so that risks reduce to an acceptable rate due to use of the most reliable devices in combination with their duplication and reservation. However, complex systems demand developing of an instrumentation and control software subsystem which allows the whole system to function as a unit organizing interaction of its components depending on environment conditions and process state. The software faults including those concerned with incorrect mathematical models application can lead to refusal of the whole system and duplication of the identical copies of the software does not allow to fix the problem in this case. One of the possible ways of reliability increasing is multi-version programming.

2. Causes of failures and statistical data on them

Producers of instrumentation and control devices supply their consumers (usually, various design and implementation companies) with all necessary procedural guidelines [8, 11] on the corresponding software development. However, development of the software is always concerned with the risk of errors at various stages of development. At the stage of the program code writing, errors revealed by the compiler are insignificant here since they come to light before input of the program module in operation. The same can be told about the gross logical errors in the program code which are always revealed at a stage of testing. Other errors which are insignificant in usual operating modes but shown when several conditions satisfy simultaneously have the greatest impact on reliability of a software system. As a rule, program modules are tested for their working capacity in extreme operating modes. At the same time, errors can be shown at achievement of maximum values of several parameters simultaneously.

Errors in complex mathematical models applied in the program code are even more “artful”. Modern instrumentation and control devices include software modules of various complexity. A software module can implement very simple or extremely complex logical principles for controlling actuators in accordance with data from many sensors and information stored in software module database. Let us consider a software module controlling the subsystem of distribution cameras of aerotanks in a city sewerage system.

Eight regulating locks are a part of an actuator subsystem. Sensors of drains level and sensors of locks state form the

instrumentation subsystem. The main function of the distribution cameras control algorithm is automatic positioning of the locks depending on given difference of drains levels in distributive cameras. A problem of this subsystem is maintenance of the given levels difference in distributive cameras by means of regulation of the regulating locks. Mathematical model for calculating the drain expense proceeding through the lock is $Q = 1.86 \cdot B \cdot (L - S)^{3/2}$, where B is width of the bottom of the lock, L – is the water level in the distributive camera, S is the Schieber valve position. Values of L and S are also estimated with use of the corresponding mathematical models. Moreover, a set of conditions for running this algorithm is given. The algorithm formulates tasks for the actuator adjusting the position of Schieber valves.

In addition, the software module contains a set of algorithms for running in emergency situations such as malfunction of sensors and actuators.

The parameters of a developed software modules must be adjusted. Incorrect program code of each of the algorithms of the software module or incorrect parameter values can lead to the fault of the software module and incorrect functioning of the whole system. Since this software module controls the supplementary functions of the system its refusal will not immediately lead to an accident of the whole system. At the same time, in the same system, there are slightly less complex modules operating its crucial elements. Failure of the module can be found by appropriate monitoring means. At the same time, incorrect operation of the module (incorrect realization of mathematical models) leads to work of the whole system in a non-optimal mode that results in fast wear, increase of risk of emergencies in other parts of system working with the raised loading and, in case of our system, to serious ecological consequences in medium-term prospect. Detection of such implicit errors is extremely complicated.

In case of refusal of the program module owing to hardware failure, efficient means of increase of reliability of system is duplication of hardware resources: sensors, servers, telecommunication channels. The violation of logical principles given by the mathematical model which does not lead to its stop will repeat on any number of its copies.

3. Methods of multi-version programming and assessment of errors emergence probability

The technology of highly reliable multi-version programming is traditionally applied in military areas, mostly in space systems. Land spacecraft control systems are equipped with the software where the separate modules duplicate functions of each other. Versions of the module are developed by independent teams of computer programmers and tested separately. Besides, different development tools are often used for each version. Versions are executed in parallel, the results of running of each of them are transferred to the auxiliary module which is carrying out the comparison of results. If results (with given tolerance) coincide, the result of one of modules is transferred to an actuator. In case of

discrepancy, for example, the overall result gets out "by a majority vote" (the odd number of module versions is required). Anyway, application of multiversions allows to reveal existence of a problem in a program code. The revealed error in the program code can serve as a signal to transfer of the system into a special emergency mode, production stop etc., up to the identification of a cause of the error and its elimination. Thus, in many cases, instrumentation and control systems do not demand existence of odd number of multiversions. Existence of at least two independently developed versions allows to reveal an error in most cases.

Let the probability of emergence of an error be equal to p_i in the i th of the version of the software module. Then the probability of simultaneous emergence of an error in all modules is $\prod_{i=1}^N p_i$ where N is the number of versions of the module and the probability of detection of an error is $1 - \prod_{i=1}^N p_i$.

Obviously, this value tends to 1 with the increase of N . Since the software modules pass through various testing procedures, the probability of error in each of versions is comparatively small. For example, if the error probability in each of two versions is equal to 0,001% then the probability of simultaneous error in both modules reduces to 0,0000001%.

Various models can be used for an assessment of estimated number of errors. For example, in [6], the following assessment of initial number of errors D_0 is offered:

$$(1) \quad D_0 = V / 3000,$$

where V is the program code volume in bits of information. In turn, this volume is estimated as $V = N \log_2 \eta$, where $\eta = \eta_1 + \eta_2$ is number of unique commands and operands of the program code, $N = N_1 + N_2$ is number of their calls in the software.

The number of errors at the m th stage of testing is estimated by the Halsted model [9] as

$$(2) \quad D_m = E^{(2/3)} / 3200,$$

where E is an estimation of the system complexity: $E = \eta_1 N_2 N \log_2 \eta / 2\eta_2$.

These complexity models and models for estimating the number of mistakes can be used as rough estimates. Let each of the M modules have some versions, V_j versions for the j th module. Let P_{ji} be the probability of no-failure operation of the i th version of the j th module. If refusal of any of modules leads to refusal of the whole system, the probability P of no-failure operations of the system can be expressed as follows:

$$P = \prod_{j=1}^M (1 - \prod_{i=1}^{V_j} (1 - P_{ji})).$$

In turn, the probability of no-failure operation can be estimated through the errors quantity (1) - (2).

4. Software system reliability optimization model

Complexity of each of modules can be considered approximately identical regardless of its exact realization. Thus, knowing complexity of the only version of each module, the assessment of probability of no-failure operation of the whole system depending on number of versions of each of modules and probability of no-failure operation P_i of the only version can be estimated: $P = \prod_{j=1}^M (1 - V_j (1 - P_j))$. At the same time, the increase in number of versions of each of modules leads to increase in cost of system. For instrumentation and control systems, we will consider accepted the number of versions of the module which does not exceed 2. We introduce the Boolean variables x_j equal to 1 if the j -th module must be duplicated and the constants C_j equal to the cost of development of the j -th module. Then, if the total budget C for development of the whole software system is known, we have an optimization problem:

$$(3) \quad P = \prod_{j=1}^M (1 - (1 + x_j)(1 - P_j)) \rightarrow \max, \\ \sum_{j=1}^M (1 + x_j) \cdot C_j \leq C.$$

Analogous optimization problems of "knapsack" type are investigated in [1, 2, 7]. In [4, 10], author propose methods able to achieve "good" (precise enough) sub-optimal solution of such problems up to millions of variables and, thus, such methods can solve problems similar with (3). For problems with monotonic objective function, greedy heuristics [3] or special agglomerative greedy heuristics [5] can be successfully implemented.

5. Conclusion

A problem of instrumentation and control systems fault-tolerance increasing cannot be completely solved with hardware duplicating only. In addition, software modules must be duplicated, too. A problem of building an optimal set of the software modules can be formulated and solved as a pseudo-Boolean optimization problem.

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THERMODYNAMIC ANALYSIS OF FRICTION AND WEAR OF ULTRAFINE-GRAINED MATERIALS

ТЕРМОДИНАМИЧЕСКИЙ АНАЛИЗ ТРЕНИЯ И ИЗНАШИВАНИЯ УЛЬТРАМЕЛКОЗЕРНИСТЫХ МАТЕРИАЛОВ

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Abstract: The conditions are substantiated for the loss of thermodynamic stability of a tribosystem and for its adaptation with a decreasing wear rate at the moving frictional contact of parts from materials with an ultrafine-grained structure produced by equal-channel angular pressing. The regularities of the influence of the structure's dispersion degree and the friction contact's temperature on the tribotechnical characteristics of ultrafine-grained materials are established theoretically and experimentally.

KEY WORDS: FRICTION, WEAR, SHEAR STRENGTH OF ADHESIVE BONDS, MOLECULAR COMPONENT OF THE FRICTION COEFFICIENT, THERMODYNAMICS, ULTRAFINE-GRAINED STRUCTURE, ADAPTATION, ENTROPY PRODUCTION, SECONDARY STRUCTURES

1. Introduction

In connection with the development of high-technology branches of industry in all developed countries, the problem of increasing the wear resistance of mechanisms and reducing power friction losses is a topical task. At present, special attention is paid to the issues related to the development of new materials for tribological units for various applications. One of the most promising research areas in the sphere of design of new materials with unique properties, including improved tribotechnical characteristics, is the development of special technologies for fabrication of ultrafine-grained (UFG) materials [1]. Titanium and its alloys in the UFG structural state produced by severe plastic deformation, in particular using the technique of equal-channel angular pressing (ECAP), have been selected as the object of study.

To date, still insufficiently studied are the tribotechnical characteristics (wear resistance, friction coefficient, shear strength of adhesive bonds, etc.), as well as the thermodynamic aspects of friction and wear of UFG materials. Resolution of these issues is topical for triboengineering.

2. Theoretical preconditions

The wear and formation of the surface layers of a tribocontact are fundamental processes inherent in any contact or tribosystem. Thus, friction can be studied on the basis of the fundamental laws of nature. In the process of friction, energy conversion takes place, therefore it is natural to consider the mechanism of friction and wear from the point of view of thermodynamics. Since friction is a non-equilibrium process, and the main phenomena occurring during friction are concentrated in the thin near-surface layer, of scientific and practical interest are the aspects of friction based on the thermodynamics of non-equilibrium processes and self-organization [2, 3].

Thermodynamic analysis allows establishing the conditions, under which an enhancement of wear resistance can be anticipated with an increasing dispersion degree of the structure of contacting materials.

The structural differences between the conventional (initial) and ECAP-processed conditions of materials lie in the dispersion degree of the structure of materials. A UFG structure produced by ECAP has a large volume fraction of grain boundaries, as compared with a coarse-grained (CG) structure, and is also characterized by a high concentration of defects (point and linear ones) in grain boundaries and in their vicinity, with a decreasing number of

dislocations inside grains [1]. Non-equilibrium grain boundaries in UFG materials, due to the presence of an ultimately high density of defects in their structure, possess an excess energy and fields of long-range elastic stresses [1]. Thus, the UFG state as a thermodynamic system is in a "more" non-equilibrium condition as compared with the CG state.

The non-equilibrium processes in a tribosystem may lead to a decrease in entropy production and consequently, a decrease in wear rate, and can run stably under the formation of dissipative structures during self-organization (adaptation) [2, 3, 4, 5]. The process of self-organization can start only after a system passes through instability [2, 3, 4, 5]. A system can lose its stability under negative excess entropy production (in accordance with a Lyapunov function [3]). For self-organization of a tribosystem, more than one independent process should occur in it [2, 3, 4, 5]. In actual systems, in addition to friction, other independent sources of energy dissipation are always present as well, such as the physico-chemical interactions of rubbing bodies with each other, environment and lubricant, which lead to a change in the composition of surface structures. In the equation for excess entropy production, this is taken into account through the dependence of heat conductivity λ on a certain parameter z characterizing the deviation degree of a material's structure from the equilibrium (for instance, the dispersion degree of a structure produced by ECAP):

$$\frac{\partial}{2 \cdot \partial t} \delta^2 S = \frac{(p \cdot v)^2}{T^2 \cdot B} \cdot \left(\frac{1}{\lambda} \cdot \left(\frac{\partial f}{\partial z} \right)^2 - \frac{f}{\lambda^2} \cdot \frac{\partial f}{\partial z} \cdot \frac{\partial \lambda}{\partial z} \right) \cdot (\delta z)^2, \quad (1)$$

where δ is fluctuation, S is entropy, T is the absolute temperature, B is the contact surface, f is the friction coefficient, p is load, v is the sliding velocity.

The first part of the expression (1) can become negative due to the sign of the second multiplier. In order for the expression (1) to become negative, the following condition should be fulfilled:

$$\frac{\partial f}{\partial z} \cdot \frac{\partial \lambda}{\partial z} > 0. \quad (2)$$

The condition (2) is fulfilled if f and λ simultaneously decrease or increase with an increasing parameter z . Non-equilibrium grain boundaries in UFG materials possess excess energy and fields of long-range elastic stresses, which leads to the intensification of relaxation processes under external action (friction), which are

reflected in mass transfer due to deformation and diffusion. A part of the entropy production caused by mass transfer can be presented in the general form:

$$\left(\frac{dS}{dt}\right)_m = X_m \cdot \rho_m \cdot W(X_m), \quad (3)$$

where X_m is the thermodynamic force causing mass transfer (the gradients of stresses or chemical potentials, respectively, for deformation and diffusion), ρ_m is the mean density of a substance participating in the mass transfer, $W(X_m)$ is the mean rate of mass transfer, dependant on X_m , which will increase with increasing X_m .

The excess entropy production under a systematic fluctuation of the parameter z will equal:

$$\frac{\partial}{\partial t} \delta^2 S_m = \frac{\partial X_m}{\partial z} \cdot \left(W \cdot \frac{\partial \rho_m}{\partial z} + \rho_m \cdot \frac{\partial W}{\partial X_m} \cdot \frac{\partial X_m}{\partial z} \right) \cdot (\delta z)^2 \dots (4)$$

The thermodynamic force of mass transfer will grow with an increasing degree of non-equilibrium (z), i.e. $\frac{\partial X_m}{\partial z} > 0$, and since

$\frac{\partial W}{\partial z} > 0$, the negative contribution to the excess entropy production

can only be made by the member $\frac{\partial \rho_m}{\partial z}$. For this to happen, the

density of the substance participating in the mass transfer should decrease with an increasing parameter z . Thus, the excess entropy production (4) can become negative, and the system can lose its stability, under the following condition:

$$\frac{\partial \rho_m}{\partial z} < 0. \quad (5)$$

A decrease in the density of a substance participating in the mass transfer can take place due to an increase in the number of dislocations and vacancies. Apparently, such a decrease in density is insignificant and cannot cause the instability of a system. A considerable decrease in the density of the substance under transfer can occur due to an increase in the content of secondary, lighter structures in it, such as oxides.

Hence, the excess entropy production for a tribosystem with a non-equilibrium condition of the contacting surfaces can become negative, and the system can lose its stability and decrease its wear rate, if the condition is fulfilled of a simultaneous decrease of the friction coefficient, heat conductivity and density of the substance participating in the mass transfer.

In order to evaluate the adequacy of the above stated results of theoretical analysis, experimental studies have been performed.

3. Research methods

CG and UFG (ECAP-processed) VT1-0 Ti and the Ti_{49,8}Ni_{50,2} titanium nickelide were used as the materials for study.

For conducting ECAP operations [1, 7], a press with a hydraulic drive DB-2432, having a force of 1.6 MN, was used, as well as die-sets with two angles intersecting at an angle Φ (90°, 110°, respectively, for VT1-0 and Ti_{49,8}Ni_{50,2}) with equal cross sections $\varnothing 20$ and 40 mm. The pressing operations were conducted at temperatures of 400-450°C via route B_C , where the billet was rotated about its longitudinal axis by 90° after each pass [1]. A total of 8 passes were made. For further microstructure refinement, one of the VT1-0 rods after ECAP processing was subjected to additional cold rolling to a strain of 75%.

In order to study the adhesive interaction, an experimental method was used [6], based on a physical model (fig. 1) which in a

first approximation reflects the actual conditions of friction and wear in a local contact.

In accordance with this model, a spherical indenter 2 (simulating a single asperity of the contact spot of rubbing solid bodies), compressed by two plane-parallel samples 1 (with a high precision and purity of the contacting surfaces), rotates under load around its own axis. The force F_{exp} , expended on the indenter's rotation and applied to a cable 3 lying in the groove of a disk 4 (with a radius R), is connected mainly with the shear strength τ_{nn} of adhesive bonds. With a view to apply this technique in the conditions of elevated contact temperatures, a special facility was designed and produced, allowing to conduct electric contact heating of the contact zone (through buses 5 isolated by spacers 6 from the enclosure, fig. 1) and ensure a temperature distribution in the near-surface layer, typical for a tribocontact. Also, methods were developed for the calibration and regulation of contact temperature, as well as for establishing the dependence of the variable τ_{nn} on the normal pressure p_m at various contact temperatures [6].

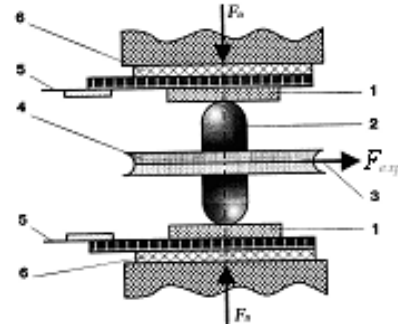


Fig. 1. Model of friction contact

As the indenter, double-sided spherical cylinders (with a radius of 2.5 mm and a height of 25 mm) were used, made from the hard-alloy tool material VK8 (8% Co; 92% WC) which is preferentially used when cutting parts from titanium and its alloys. VK8 has rather high high-temperature strength and heat resistance (up to 850...900 °C), which enabled evaluating the tribotechnical properties of the materials under study at elevated contact temperatures.

The samples for study (with a diameter of 20-25 mm and a height of 6 mm) were made from CG and UFG Ti and its alloy. The surface roughness of the samples and indenter $Ra = 0.63 - 0.80 \mu m$. The angular rotational velocity of the indenter around its axis was $0.1 s^{-1}$. The time of heating-up and testing of the sample at this temperature did not exceed 1 min. All the measurements of the tribotechnical characteristics for each condition at room and elevated temperatures were conducted on the same samples.

The shear strength of adhesive bonds τ_n was derived from the relationship [6]:

$$\tau_{nn} = \frac{3}{4} \cdot \frac{F_{exp}}{\pi} \cdot \frac{R}{r_{imp}^3}; \quad (6)$$

where r_{imp} is the radius of the impression (indent) made on the tested samples, mm.

Due to the small sizes of the impression, it was assumed that the normal pressure effecting action on the sphere surface, were constant and equal in the whole impression area. The deformation of the spherical sample, which was harder as compared with the plane sample, was neglected. The normal pressure at the contact p_r (MPa) was estimated as follows [6]:

$$p_r = \frac{F_n}{\pi \cdot r_{imp}^2}, \quad (7)$$

where F_n is the compressing force, N.

If plastic deformation is present at the tribocontact, the shear strength of adhesive bonds τ_{nn} is directly proportional to the ultimate normal pressure p_{rn} at the contact [6]:

$$\tau_{nn} = \tau_0 + \beta \cdot p_{rn}, \quad (8)$$

where β is the strengthening coefficient of molecular bonds under the action of compressing pressure, τ_0 is the shear strength of adhesive bonds in the absence of a normal load.

The adhesion component of the friction coefficient f_M [6] was determined according to the formula:

$$f_M = \tau_{nn}/p_{rn} \quad (9)$$

In addition to studies performed on the adhesion tester, experiments were also performed on a friction testing machine in order to determine the friction coefficient and wear rate of the materials under study in the pin-on-disc contact configuration. The testing conditions are presented below.

The disc was made from AISI 52100 (analogous to ShKh6), and the cylindrical samples $\varnothing 2 \times 20$ mm were made from the materials under study: UFG and CG VT1-0 and titanium nickelide. The disc moved in reciprocating motion around its axis by an angle of 45° . The vertical force was 5 N. The sliding velocity of the disc upon the cylinder was 0.1 m/s. The friction was dry. The test values for the friction coefficient were recorded in a computer in the form of oscillograms. Wear (the lost volume in mm^3) was measured, and the wear rate ($\text{mm}^3/\text{N}\cdot\text{m}$) for the cylindrical samples was calculated.

To study the microstructure, as well as the chemical and phase compositions of the tested samples, the following methods were used: optical metallography (OM) (NEOPHOT 21), transmission electron microscopy (TEM) (JEM-100B) and scanning electron microscopy (SEM) (JSM-6490LV), X-ray photoelectron spectroscopy (XPS) (ES 2403 M-T).

4. Experimental results and their discussion

The studies on the effect of the structure's dispersion degree and the friction contact's temperature on the adhesion parameters were performed on the samples of VT1-0 in three conditions: the initial condition, the condition after ECAP and the condition after ECAP + cold rolling. Their average grain size was 15, 0.3 and 0.1 μm , respectively (fig. 2). The samples from the titanium nickelide were also subjected to ECAP. Their average grain size was 50 and 0.3 μm , in the initial condition and in the ECAP-processed condition, respectively.

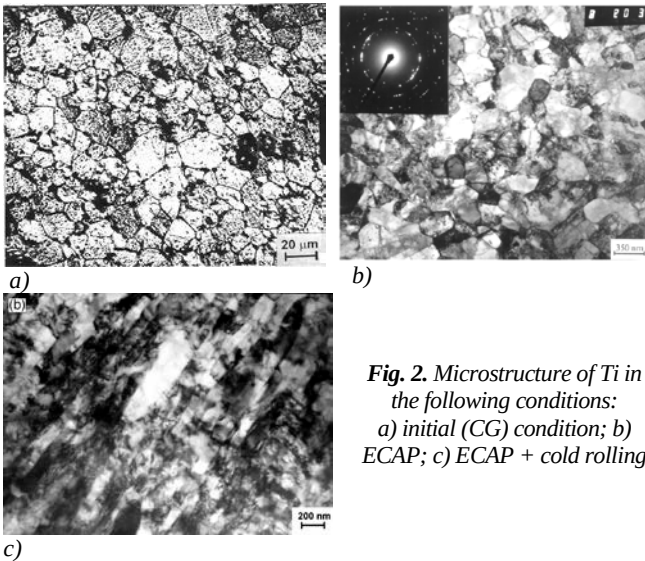


Fig. 2. Microstructure of Ti in the following conditions: a) initial (CG) condition; b) ECAP; c) ECAP + cold rolling

The functional dependencies have been revealed between the structure's dispersion degree, the temperature and the tribotechnical parameters: τ_{nn} , p_{rn} , f_M (fig. 3, 4).

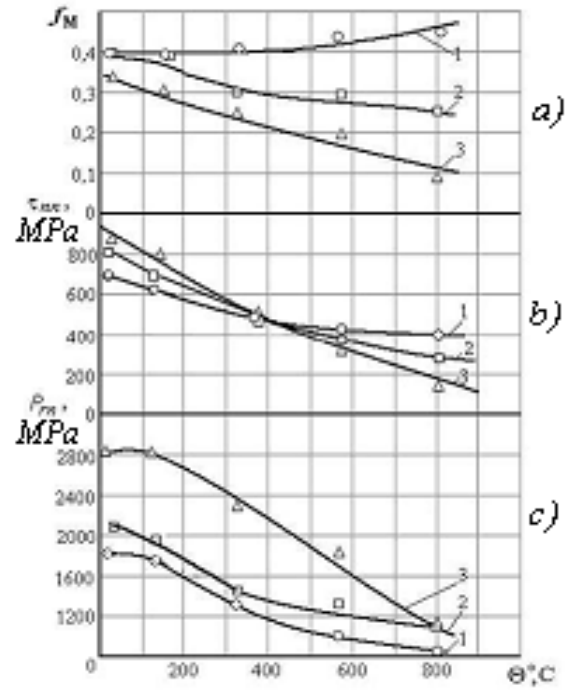


Fig. 3. Effect of the temperature of the friction contact on the tribotechnical characteristics of the VT1-0 titanium: a) f_M ; b) τ_{nn} ; c) p_{rn} ; 1 – initial condition; 2 – after ECAP; 3 – after ECAP + cold rolling 75%

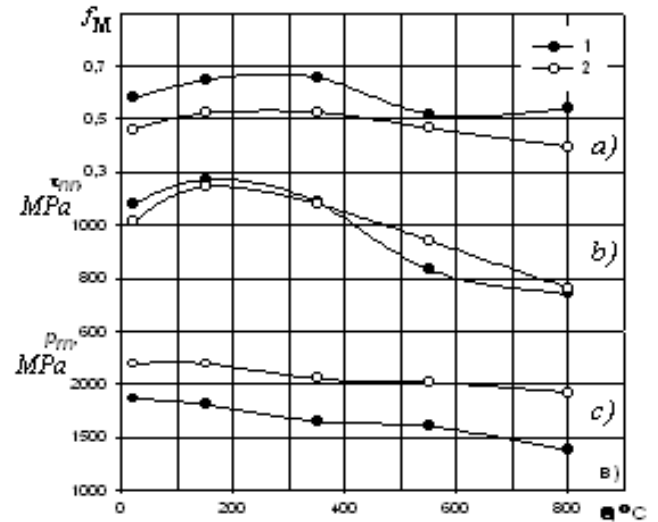


Fig. 4. Effect of the temperature of the friction contact on the tribotechnical characteristics of the titanium nickelide (1 – initial condition, 2 – after ECAP): a) f_M ; b) τ_{nn} ; c) p_{rn}

The formation of a UFG structure in the VT1-0 titanium reduces f_M and decreases its tendency to seizure (fig. 3). The smaller is the grain size and the higher is the contact temperature, the stronger is this effect. The value of the critical contact temperature has been determined as $\approx 350^\circ\text{C}$. Above this temperature, an increase in the dispersion of titanium's structure leads to a decrease in τ_{nn} as compared with the CG state, which can be accounted for by an intensive relaxation of stresses in UFG Ti due to recovery processes and by a more intensive appearance of secondary structures (titanium oxides) at the friction contact, which act as a protective film preventing seizure of contact surfaces. In the $\text{Ti}_{49.8}\text{Ni}_{50.2}$ intermetallic alloy, structure refinement also reduces f_M .

Tests in the pin-on-disc configuration also confirmed the decrease in the average values of the friction coefficient for VT1-0 and $Ti_{49.8}Ni_{50.2}$ processed by ECAP, as compared with their initial condition (fig. 5). It was established that UFG materials had an enhanced wear resistance as compared with their CG counterparts.

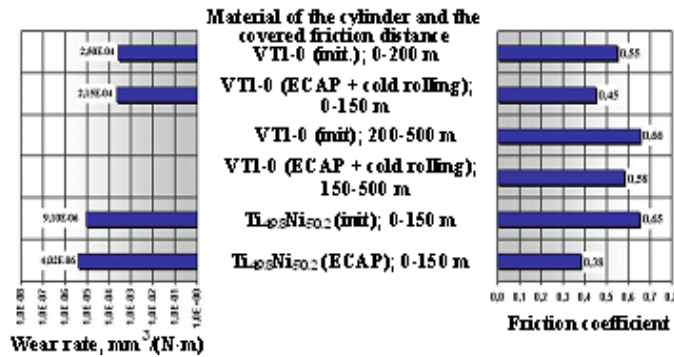


Fig. 5. Wear rate and friction coefficient of the materials under study, when tested in the pin-on-disc configuration

The microstructural studies of the friction contact surfaces by OM and SEM revealed the absence of significant growth of UFG Ti at contact temperatures up to 800 °C, which is related to the equilibrium of the processes of recrystallization and structure fragmentation in the zone of plastic contact under high loads.

On the basis of the XPS survey spectra (one of the spectra is shown in fig. 6), it was found that the surface of the samples from CG and UFG VT1-0 Ti after adhesion tests had identical qualitative element compositions, but different quantitative compositions. Using high-resolution spectra for the Ti 2p sublevel (one of the spectra is shown in fig. 7), it was established that the samples from CG and UFG Ti after tribotechnical tests did not contain metallic Ti on their surface, but did contain this element within the TiO_2 compound. It was revealed that on the surface of UFG Ti after tribotechnical tests there were twice as much TiO_2 titanium oxides as compared with its CG counterpart. The quantity of titanium oxides increased with an increasing contact temperature. Titanium oxides, acting as a protective film, prevent from seizure of contacting surfaces and promote a decrease of the friction coefficient.

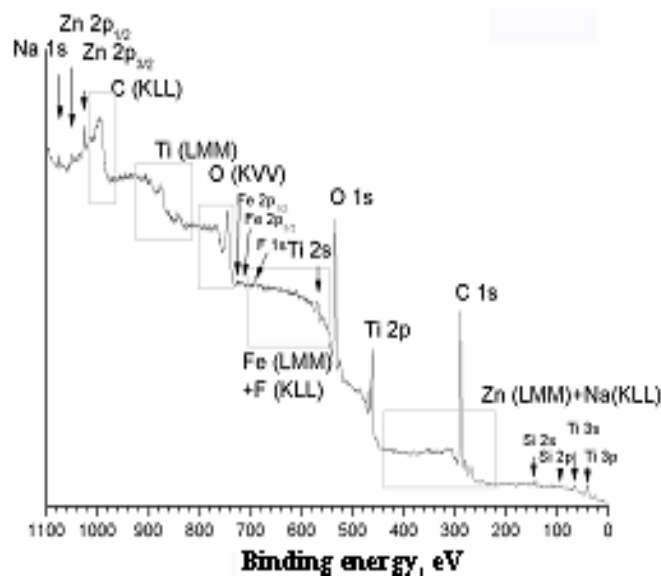


Fig. 6. Example of XPS survey spectrum for UFG Ti after tribotechnical tests at a contact temperature of 800 °C

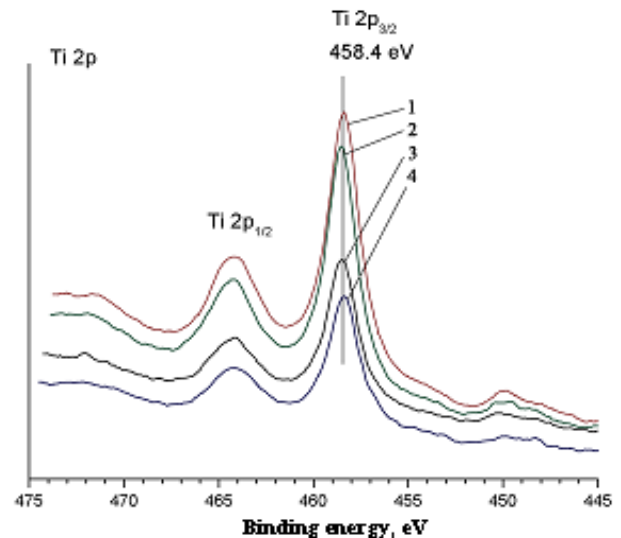


Fig. 7. High-resolution spectra of the Ti 2p sublevel for UFG Ti samples: 1 – $\Theta = 800^\circ C$; 2 – $350^\circ C$; 3 – $20^\circ C$; 4 – prior to tribological testing

It follows from [5] that in the UFG state, the heat conductivity of Ti (as well as its electric conductivity) is smaller than in the conventional state, which appears to be natural due to an increased content of vacancies in the UFG structure.

5. Conclusions

The obtained experimental data have allowed to account for a decrease in the wear rate of UFG materials (using Ti and its alloy as an example) by a simultaneous decrease in the friction coefficient, heat conductivity and density of a substance participating in mass transfer. Thus, these data have confirmed the results of the thermodynamic analysis of the effect of the structure's dispersion degree and temperature on the tribotechnical characteristics of Ti and its alloys. This opens up new opportunities for improving articles from UFG materials.

ACKNOWLEDGEMENT

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UV DEGRADATION OF POLYMER-MATRIX COMPOSITES PA + GF

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Abstract: The present article deals with monitoring the changes in the mechanical properties of composites with polymer matrix. The composite was formed from the PA matrix and glass fibers. The composite contains 10 – 30 % glass fibers. The mechanical properties, tensile strength and flexural strength were evaluated on samples of the composite before and after UV radiation on the sample. The largest decline endpoints was recorded in 500 hours of UV exposure. Light microscopy was evaluated distribution of glass fibers in the polymer matrix and the presence of cracks caused by UV radiation.

Keywords: UV DEGRADATION, POLYMER-MATRIX COMPOSITES, MECHANICAL PROPERTIES, GLASS FIBERS

1. Introduction

Composite materials are composed of two or more chemically different components, of which at least one, referred to as matrix, it is continuous. The second component is dispersed in the matrix and the filler is referred to as. Hybrid composites are materials which are formed of three or more components. The hybrid matrix comprises two types of polymers, hybrid filler is composed of two or more types of fillers. In addition to the filler and matrix composites contain a third component, referred to as the intermediate phase. The term intermediate phase is often wrongly confused with interfacial interface. In the past, some of the additives, fillers was glad because, like additives (e.g., stabilizers, flame retardants, lubricants, nucleating agents), and the fillers are added to polymers to improve their properties. However, while it is a priority task additives modify the physical and processing properties of polymers (viscosity, the proportion of crystalline phase, thermal stability and etc.), addition of fillers to polymers is followed primarily improve the mechanical. The resulting composite is therefore compared the original polymer matrix often diametrically different physico - mechanical properties. Depending on the type of composite, the filler content varies widely. While in polymer nanocomposites nano filler content generally does not exceed a few percent by weight (3-5% by weight), in the case of composite fiber it is much higher and may be up to 80-85% by weight. The selection of the filler, and the content in the composite is always facing in order to maximize the improvement of the desired properties [1, 2, 3].

Polymeric materials are perhaps the most sensitive to material changes in the chemical structure under external influences, and the resulting physical and especially the mechanical and chemical properties. The most significant factors that trigger the chain mechanism of chemical change in the polymeric material to UV light, heat, oxygen, and the presence of particular of ozone. To accelerate chemical degradation processes typically it contributes the mechanical stresses and the possible presence of chemicals, in particular organic solvents. Testing degradation of polymeric materials, generally well-established, the term aging of polymers, is one of the most important tests for estimating the life of the polymeric product. Ageing may be made either in real conditions of use of the polymer in a particular application, or use artificial accelerated aging conditions. Accelerated aging methods provide significantly faster test results than testing natural aging, because many times it is not possible to carry out tests of natural aging, especially for reasons of time. Test methods of susceptibility testing of polymeric materials degradation (aging) reflect the diversity of their application utilization, especially conditions in which the finished products will be used. It must also be taken into account the susceptibility of different types of polymers to each initiation of degradation mechanisms. Rubber products are generally more susceptible to degradation and thermooxidation the action of ozone, plastics, in particular polyolefins, are susceptible to ultraviolet radiation. When choosing a method for testing polymeric

material to be considered application area of the finished product as well as the characteristics of the polymer. It is utterly unrealistic to test the rubber seal under the heating element on the light stability, but it is necessary first to know its resistance to thermal, respectively. He thermooxidation action. Conversely, window profiles, it is necessary to test the light stability and should be considered as relatively high temperatures during the summer months. The components in the automotive industry have generally resist and ultraviolet radiation and high temperatures [4, 5, 6].

2. Experimental methods and materials

As an experimental material was used a composite of polymeric matrix (PA + PAI) and filler (glass fiber). The glass fiber strand have manufacturing marking GF 672, fiber diameter is 10 mm and the fiber length of 4 mm. They were supplied by three types of composite to be different in filler loading (10 %, 20 % and 30 %). It is a modern material that should be used in interior and exterior of cars. It should also resist UV radiation due to the addition of UV stabilizers. The experimental implementation of mechanical and thermal tests, samples in the form of rods and paddles which were produced from the granules of the polymer injection molding technology.

Testing degradation of polymeric materials is one of the most important tests to the lifetime of polymer product. Ageing tests can be either in real conditions of use of the polymer in a particular application, or using artificial accelerated ageing conditions. Accelerated ageing methods provide test results significantly faster natural aging tests. Testing is based on exposing test bars to man-made climate. After a fixed interval of exposure changes are detected in end points (aesthetic, physical, electrical, etc.). The apparatus for man-made weather ageing (Fig. 1) ensure continued maintaining of artificial climatic conditions (day and night cycles, changing humidity, drought and wet, etc.)



Fig. 1 SolarBox 1500 E with flooding

A source of light radiation guarantees a radiant flux of radiation intensity 550 W m^{-2} . The source of light is a xenon arc lamp, but other sources of radiation are allowed too. The device must be equipped with a thermometer built into the black panel, which senses the temperature of the black panel. The black panel temperature of exposure time was selected at 65°C , the liquid phase lasted for 102 minutes and the wet phase for 18 minutes. If it

necessary wetting by distilled or deionised water can be applied. The numbers of man-made climate factors that simultaneously affect the test bars is selected by the test program. Test runs continued for a period fixed in the testing program. The duration of the test was 500, 750 and 1000 hours.

3. Results and discussion

The test samples were evaluated by the selected mechanical parameters (tensile strength and hardness) regarding the effects of UV radiation. The same parameters were assessed after 3 runs (500, 750 and 1000 hours) of UV radiation acting on the sample. The test also included evaluation of the structure and changes in the structure before and after UV irradiation.

Samples for the structure test were embedded in Bakelite in the first step and then cut and polished. Grinding of the samples was carried out using the device Struers Tegra Pol-15 under a program designed for polyamides. SiC abrasive paper with grain size 500, 1 200 and 4 000 was used for grinding. Each grit sandpaper was used to grind the sample for 1 minute. Grinding was followed by polishing using Mol plate for 3 minutes. This was followed by 2 minute polishing with Nap-B, and finally polishing was finalized using wet disc and Chem-OP-S (diamond slurry) for 1 minute. The samples prepared in the above-mentioned way were evaluated for structure changes by light microscope Neophot 32.

A tensile test was performed using the device WDW 20. The speed of a moving jaw was set at $1 \text{ mm} \cdot \text{min}^{-1}$ with. The sample was pinned to the jaw and force was exercised in the longitudinal axis until the sample break. We measured the maximum force required to break the test samples. From the acquired data, we calculated the tensile strength, σ_M (Fig. 2).

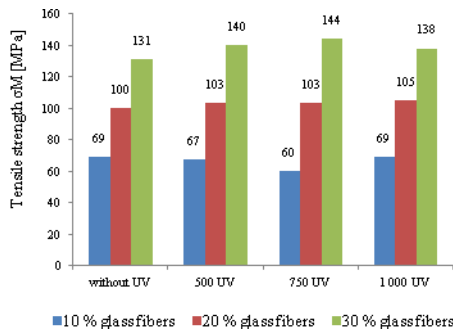


Fig. 2 Effect of UV radiation on the change in tensile strength

Figure 2 shows that the highest tensile strength of the composite is reached with 30% glass fiber content on the other hand the smallest tensile strength composite with a filler content of 10%. It follows that the strength characteristics of the composite depends mainly on the content and distribution of the glass fibers in the polymer matrix. UV radiation is the strength values did not change significantly. The filler content of 10% of the original σ_M was 69 MPa after 500 and 750 hours exposure to UV radiation σ_M slightly decreased at 67 and 60 bar, but under the action of UV radiation for 1000 hours, the σ_M returned to the original value of 69 MPa. At 20% and 30% filler content, the strength values slightly increase. Since a partially crystalline PA, stroke causes the chains straighten it, undergoing its subsequent solidification. And we can also say that UV radiation can cause partial crosslinking chains and therefore also with increasing UV exposure increases the strength characteristics of the composite.

Hardness test was conducted durometer INNOVATEST NEXUS 3002XLM-INV1. Loading force was set to 250 kP, injection time was 10 seconds and the indentation diameter balls of 5 mm. Measured by the average of the indentation beads. The microscope was counted using a scale diameters which are

perpendicular to each other, then the resulting hardness was calculated. Each sample was made 5 measurements. The final hardness is shown in Figure 3.

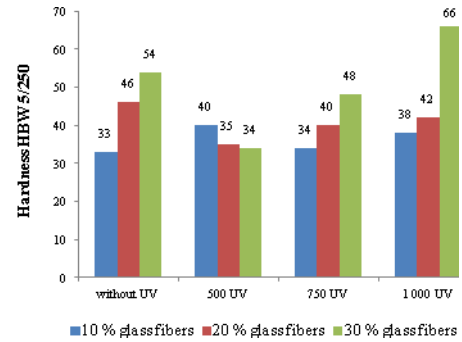


Fig. 3 Effect of UV radiation on the change in hardness

Hardness (HBW) of the composite depends mainly on the content and distribution of the glass fibers in the polymer matrix. HBW largest composite reached the 30% filler loading, whereas in the matrix occupy the bulk of the glass fibers as the filler content of 10%, which was occupying a larger volume of polymer matrix. The filler content of 10% HBW value slightly fluctuated. After 500 hours of UV HBW is slightly increased, after 750 hours of UV HBW it decreased to its original value, and after 1000 hours of UV irradiation was again to the small increase. At 20% and 30% filler content HBW hand the value after 500 hours of UV irradiation, and then decreased gradually decreased. It could result in a partially crosslinked chains to UV radiation. HBW values depended mainly from the point at which the measurement was carried out, ie whether it was a place where there was more accumulated fiberglass or was it a polymer matrix. A 3D CAD data of a part are imported into the procedural software of the printer EOSINT M 270¹. Software designed to the data preparation allows choosing the appropriate thickness of production layers with regard to accuracy / resolution and speed of production (0.020 mm or 0.040 mm – thinner layer means higher accuracy, but longer production time).

The experiment also included evaluation of the structure of the composite PA + GF before and after UV irradiation by a light microscope. We monitored homogeneity of the composite, the manner of distribution of glass fibres in the polymer matrix, and cracking caused by UV radiation.

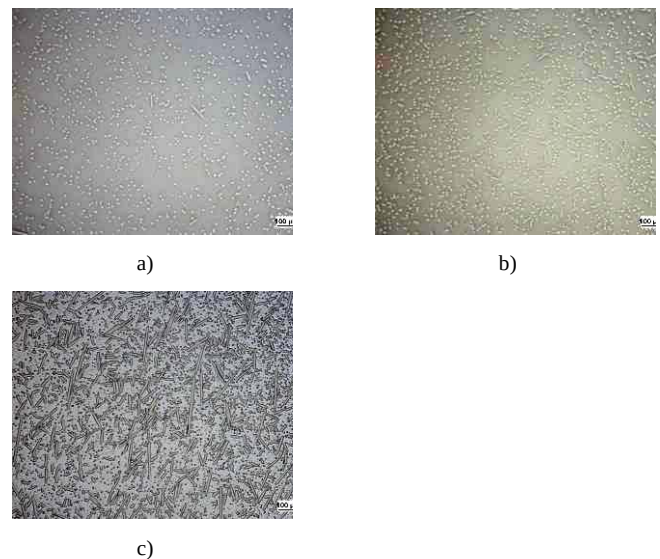


Fig. 4 Distribution of glass fibers in the polymer matrix
a) 10%, b) 20%, c) 30%

The filler content of 10%, the structure more evenly - glass fibers are evenly distributed in the polymer matrix. Fiber size was also about the same. To 20% filler content sites began to appear smaller clusters of glass fibers and emptier place in the matrix. Size fiberglass was also maintained at the approximate size. At 30% filler content, the structure of the least uniform. Fiberglass seats were piled on each other. Processing technology will brake the fibers into smaller pieces, so the material was located fibers of different sizes. Different size glass fiber in a polymer matrix was dependent on its percentage (Fig. 4).

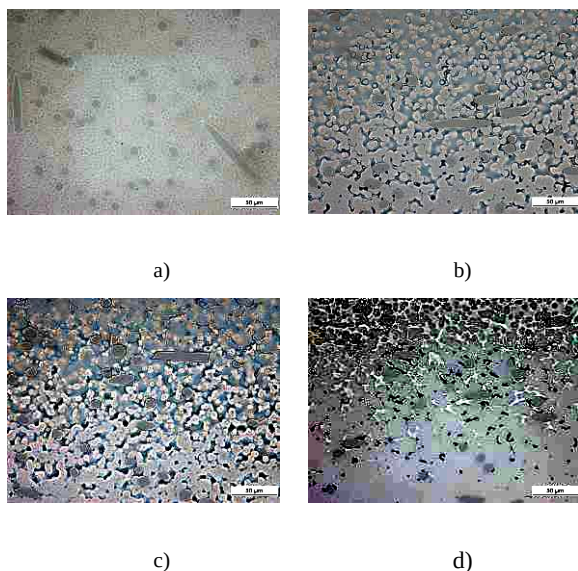


Fig. 5 The action of UV radiation on the degradation of the polymer composite, the glass fiber content of 10%

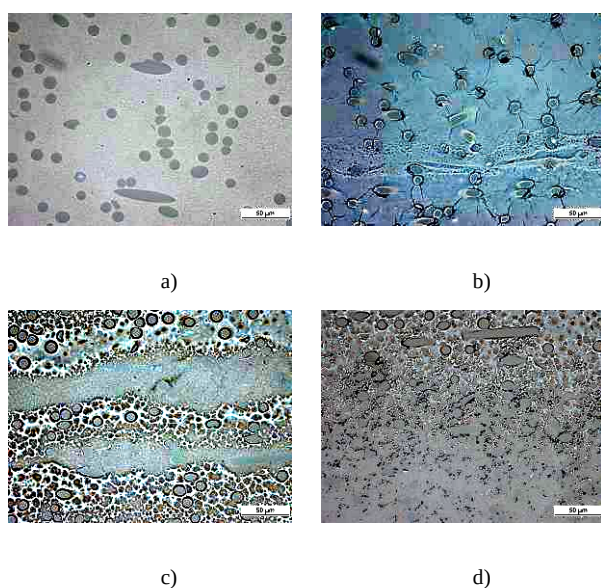


Fig. 6 The action of UV radiation on the degradation of the polymer composite, the glass fiber content of 20%

UV radiation caused us changes in structure and material degradation. Fibers started to separate from the matrix and pulled out and left by a row in the blanks - hole. At higher glass fiber content had holes tend to be linked. The fibers are broke, segregated and were pulling without residue matrix, due to poor adhesion interface fiber – matrix (Fig 7). Degradation is gradually spread from the material surface to the center. The material causing rupture of which initiates have just glass fibers and the cracks gradually spread from the surface of the matrix (Fig.6 b, c). Coloring cracks us determine its depth. At the beginning of fine hairline cracks emerged that the picture can be seen as white with a slight hint of blue. Prolonged exposure to UV radiation has been associated crack

spread and in depth. These cracks can be seen in the figures as deep black. The biggest changes in the structure (degradation) we can see a material with 10% glass fiber content, where most of the matrix to which the UV radiation is the most evident effect (Fig. 5).

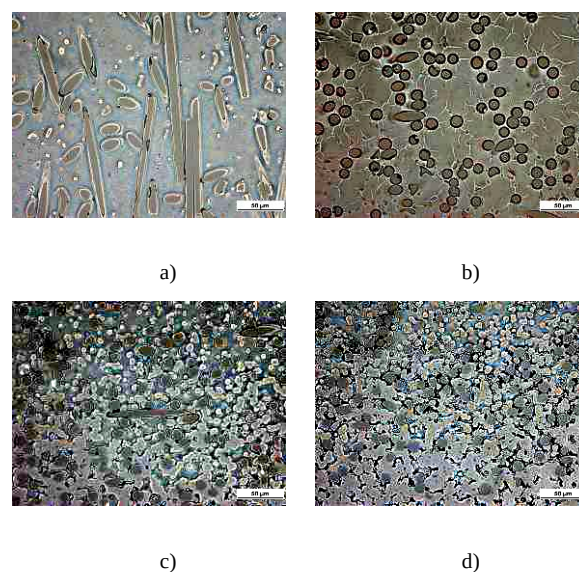


Fig. 7 The action of UV radiation on the degradation of the polymer composite, the glass fiber content of 30%

The optimum amount of filler for the composite is a glass fiber content of 30%, whereas the content of the best values were registered endpoints. As for the structure, are in the filler content of a site having marked heterogeneity in the distribution of the filler, be toxic to the mechanical properties of the composite. UV radiation is one of the most aggressive modes of degradation of polymers, which in the case of the composite expressed considerable degradation of the matrix in the glass fiber content of 10% even at the time of UV radiation 500 hours.

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MODELING AND STUDY OF THE PROCESS OF BILLETS EXTRUSION WITH ADDITIONAL BACK-PRESSURE IN EQUAL CHANNEL STEP MATRIX

МОДЕЛИРОВАНИЕ И ИССЛЕДОВАНИЕ ПРОЦЕССА ПРЕССОВАНИЯ ЗАГОТОВОК С ДОПОЛНИТЕЛЬНЫМ ПРОТИВОДАВЛЕНИЕМ В РАВНОКАНАЛЬНОЙ СТУПЕНЧАТОЙ МАТРИЦЕ

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Abstract: This work is devoted to the study of stress-strain state and power parameters in the simulation of the process of extrusion billets with additional back-pressure in equal channel step matrix. Analyzing the obtained results we can conclude that the matrix without backpressure cannot achieve complete closing of internal defects of a deformable metal. The backpressure created by the increase of the roughness of the output channel of the matrix, has a beneficial effect on the stress-strain state of the metal, which in turn allows you to provide the best structured deformable metal

KEY WORDS: EXTRUSION, EQUAL CHANNEL STEP MATRIX, STRESS-STRAIN STATE, POWER PARAMETERS, SIMULATION.

Introduction

One of the promising methods of obtaining metal from sub-ultrafine grained structure is equal channel pressing in angular and step matrices. Thus it is proved that if the compression of the metal to be implemented in equal channel angular matrix with backpressure, it creates a more favorable stress-strain state to produce the metal with sub-ultrafine grained structure in comparison with the pressing in this matrix without backpressure. In works [1-4] were studied various investigations of this kind of deformation.

One of the options to create a backpressure in the pressing process of the metal in equal channel angular matrix is the narrowing of the output channel of the matrix. During compaction of metal in equal-channel step matrix, unlike in the angular matrix, the pressure already created by the presence of the second junction of the channels of the matrix. The additional backpressure during equal channel pressing in step matrix can be achieved, as with angular pressing by narrowing the output channel of the matrix, or through the use of this matrix with the output channel roughness higher than the surface roughness of the input and intermediate channels of the matrix.

This work is devoted to the study of stress-strain state and the power parameters in the simulation of the process of extrusion billets with additional backpressure in equal channel step matrix in the software package DEFORM to determine optimum conditions to create a more favourable stress-strain state for obtaining a metal from sub-ultrafine grained structure with little energy consumption..

Study of stress-strain state

The stress-strain state during compaction in equal-channel step matrix with the backpressure was analyzed according to the results of stress distribution, strain intensity and force of deformation.

The presence of internal compressive stresses positive effect on the brewing internal defects and the quality of the metal (fig. 1). Comparative analysis of the stress distribution over the cross section of the workpiece shows that mainly dominated by compressive stresses. The overall compression scheme provided in the most part of the cross section, guarantees the absence of macro- and microcracks in the metal and conducive to the maximum degree of plasticity of a deformable workpiece.

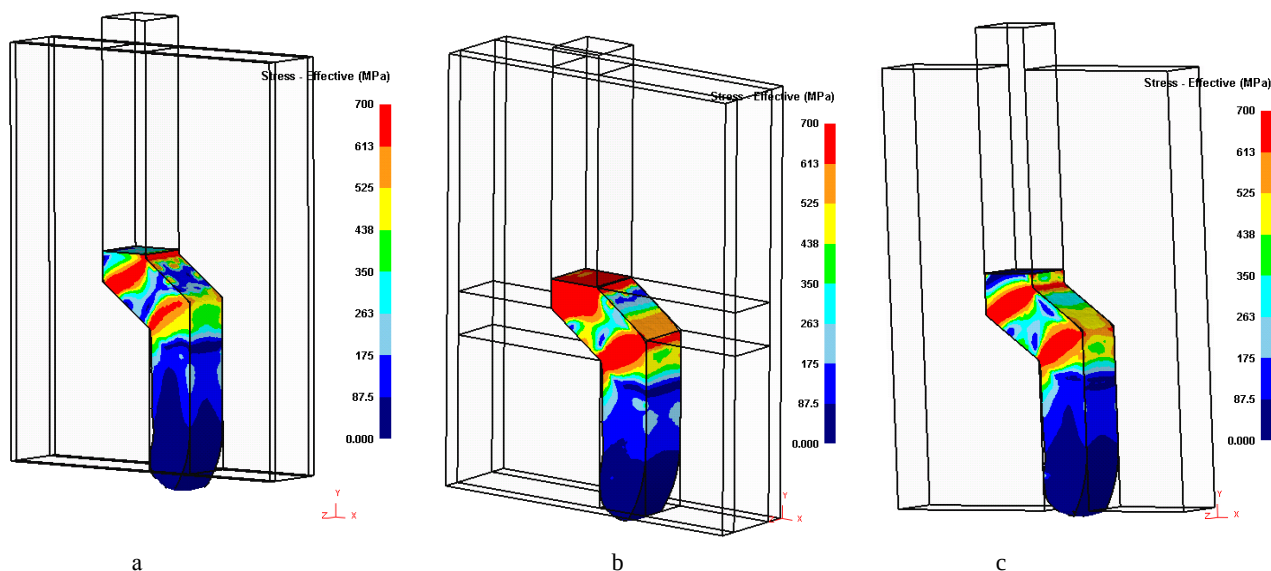


Fig. 1 - Stress distribution: a) with narrowing output channel, b) with different degree of roughness, c) without backpressure

The distribution of equivalent stress shows that the maximum value reaches at the junction of channels. In the matrix with a narrowing output channel maximum value of equivalent stress reaches 700 MPa at the junction of channels; in an inclined channel prevails to 280 MPa, in the third channel equivalent stress is reduced from 175 to 0 MPa (fig. 1a). In the matrix with different roughness maximum value of equivalent stress reaches 700 MPa,

after the first junction of channels it is 263 – 350 MPa, and after the second is reduced to 0 MPa (fig. 1b). However, equivalent stress in the third channel different from the previous example: here the area is exposed to tension, much more. In the matrix without back pressure maximum value of equivalent stress equal to the value of the previous matrices and after the second junction channels in the matrix, value is reduced to zero (fig. 1c).

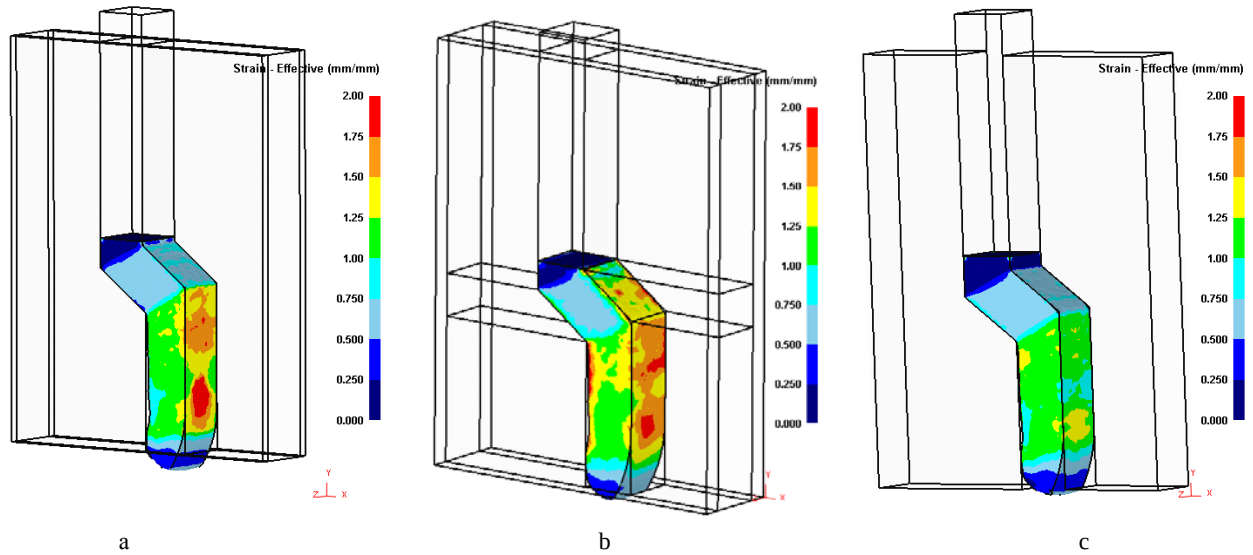


Fig. 2 - Strain distribution: a) with narrowing output channel, b) with different degree of roughness, c) without backpressure

Analyzing the strain distribution we can say that the increase in the coefficient of friction between the workpiece and the tool leads to increased efforts of deformation (fig. 2).

In the first two cases, the largest equivalent strain is achieved when workpiece is moving from the second channel in the third and its value is 0.75 to 1.0. In the matrix with narrowing output channel, the average value of equivalent strain is in the range from 1.0 to 1.25 (fig. 2a). In the matrix with different roughness with the

increase of the coefficient of friction is significantly increased and the accumulated deformation, which averages 1,0 – 1,50; sometimes, on the inner surface of the third channel, reaches 2.0 (fig. 2b). In the matrix without backpressure the value of equivalent strain is in the range 0,75 - 1,25 (fig. 2c). The figures show that the matrix with different degrees of roughness can increase the value of equivalent strain.

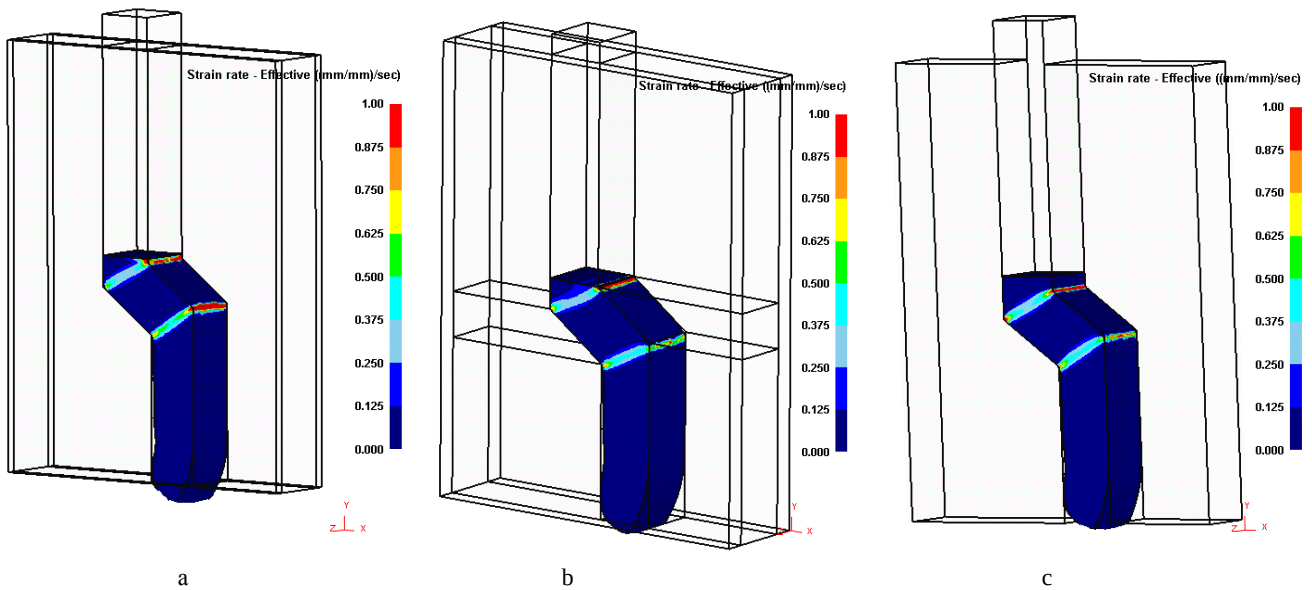


Fig. 3 – Shear strain distribution: a) with narrowing output channel, b) with different degree of roughness, c) without backpressure

The analysis of the distribution of shear strain shows significant strain localization at the zone of intersection of the channels and near the borders of the fracture profile of the matrix, hence, the workpiece passes through the localization zone of intense shear deformation.

Study of extrusion force

Then was examined the effect of narrowing channel and increasing of roughness degree of the channels on the force of deformation. This dependence will be determined from the graphs that have been constructed according to the simulation results.

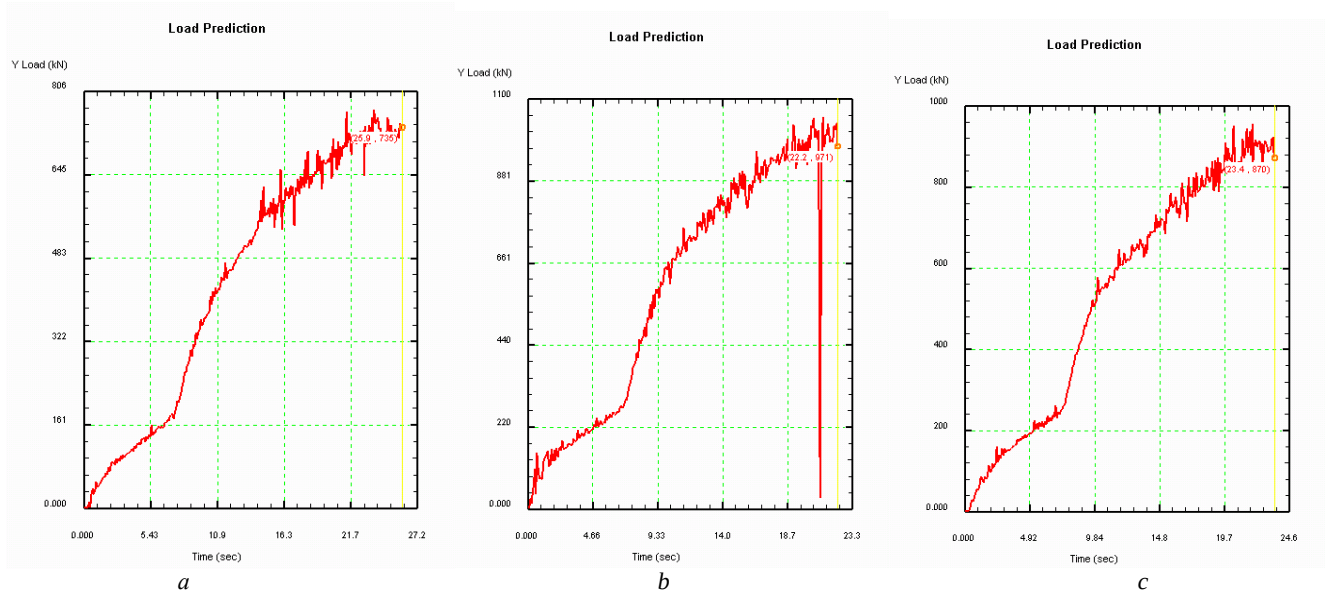


Fig. 4 – Force of deformation: a) with narrowing output channel, b) with different degree of roughness, c) without backpressure

Fig. 4 shows that the force is zero until the moment when the workpiece stops on the first joint in the matrix. The variation of these dependences shows that during the compression in the step matrix occurs in a two-step increase in force. At the initial stage the increasing force related to overcoming resistance in the first joint of channel in matrix. The second joint of the channel leads to the next stage of force increasing. Further, the force increases uniformly due to the fact that the volume of deformed metal.

The use of equal-channel step matrix with narrowing output channel the maximum force is 735 kN, while the curve increases smoothly (fig. 4a). In the matrix with different degrees of roughness, due to the increase of the friction coefficient in the output channel, the value of force increases to 971 kN, the curve is on a steeper trajectory, since a higher coefficient of friction increases the deformation resistance (fig. 4b), but this value is not significantly different from the value of the force when using a matrix with narrowing the output channel. In the matrix without backpressure the maximum force is 870 kN (fig. 4c).

Conclusions

Analyzing the obtained results we can conclude that the matrix without backpressure cannot achieve complete brewing

internal defects of a deformable metal, unlike matrices, which uses the backpressure. The application of the narrowing channel, as a way of additional backpressure in the forming process is not quite acceptable, as is a reduction of the original size of the workpiece, and this leads to the fact that after each cycle of deformation it is necessary to change the tooling. The backpressure created by the increase of the roughness of the output channel of the matrix, has a beneficial effect on the stress-strain state of the metal, which in turn allows you to provide the best structured deformable metal.

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MODELING AND OPTIMIZATION OF ELECTROCHEMICAL MACHINING OF 321-STAINLESS STEEL USING RESPONSE SURFACE METHODOLOGY

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Abstract: This paper demonstrates a systematic approach for achieving comprehensive mathematical models for electrochemical machining (ECM) of 321-stainless steel based on the response surface methodology (RSM). Machining voltage, tool feed rate, electrolyte flow rate and concentration of NaNO₃ solution were considered as the machining parameters while material removal rate (MRR) and surface roughness (Ra) were considered as the process responses. Experimental plan was performed by a central composite design (CCD). The proposed mathematical models statistically have been evaluated by analysis of variance (ANOVA). Analysis shows that the RSM method has been appointed properly as the design of experiments (DOE) method for resolving curvature in ECM process responses. Also, the optimal machining parameter for single optimization of MRR and Ra is determined by desirability function. The results showed that the proposed approach is an effective and suitable way for modeling and optimization of the ECM machining process.

Keywords: ELCTROCHEMICAL MACHINING, MODELING, OPTIMIZATION, RESPONSE SURFACE METHODOLOGY, DESIRABILITY FUNCTION

1. Introduction

ECM is a modern and non-traditional machining contributing significantly in various industries from consumer product to more sophisticated, high-tech applications and to produce micro to macro scale products. Moreover, ECM gives advantages over other conventional and non-conventional machining processes. As a case in point, conductive materials regardless of their hardness and toughness can be machined with a tool which is not harder than workpiece; there is especially no tool wear. In view of the fact that in this cold process there is no contact between cathode and anode, products without any residual stress and heat affected zone (HAZ) can be machined (Rumyantsev and Davydov, 1989; Rajurkar et al., 2006; Huang and Liu, 2014).

Even though traditional methods for conducting experiments such as trial-and-error, best-guest approach and one variable at a time (OVAT) still common (Neto et al., 2006; Bhattacharyya and Munda, 2003), these methods are time consuming and incapable of detecting the interactions between variables (Montgomery, 2009). Thus, implementation of design-of-experiments (DOE) method has increased in various manufacturing processes (El-Taweel 2008; Haridy et al. 2011). Response surface methodology, RMS, is capable of resolving curvature in the output associated with each input, detecting interactions effects and establishing mathematical models with suitable sets of experiments (Bhattacharyya and Sorkhel, 1999; Malapati and Bhattacharyya, 2011; Munda and Bhattacharyya, 2008; Munda et al., 2007).

However, the ECM process involves several physical and chemical phenomena and a number of process parameters that make it difficult to model the process (Hinduja and Kunieda, 2013). Consequently, experimental investigations, DOE, statistical and optimization approaches play a vital part in selection of proper selection of parameters setting which influence the machining performance considerably (Venkata Rao and Kalyankar, 2014).

There are researches that had been investigated this process experimentally and offer some excellent results and approaches for modeling and predicting machining conditions; still, much more experimental studies must be conducted to cover wide range of materials and methods for optimization and improving machining performance. The purpose of this research is mathematically modeling ECM process parameters, i.e. machining voltage (x_1), tool feed rate (x_2), electrolyte flow rate (x_3) and electrolyte concentration (x_4) on machining criteria, i.e. MRR and Ra of 321stainless steel. This kind of steel contains titanium which making it an excellent choice for prolonged high temperature applications such as aircraft exhaust stacks, manifolds, welded equipment, jet engine parts and

so on. Response surface methodology (RSM) is also used for correlating and analyzing the various machining parameters on the response; therefore, mathematical models develop through RSM. In addition, the adequacy of the developed mathematical models has also been tested by the analysis of variance (ANOVA). Finally, optimal machining parameters for achieving maximum MRR and minimum Ra are determined.

2. Experimental procedure and details

2.1. Set-up and machine

The experiments were carried out on home-developed machine. This machine was set up in this investigation shows in Fig. 1 consists of four well-designed units, i.e. machine, electrolyte, control and power supply unit. The tool feeds forwards and backwards using the AC servo motor through a ground precision ballscrew with pitch of 2.5 mm and precision linear guides. Machining place was built by Plexiglas with a door provided more convenience for changing the workpiece. All used connectors, valves and hose made of 316 stainless steel, PVC and polyethylene; thus, the electrolyte composition does not change moving through these parts. Two PVC tanks have duty for supplying and storing electrolyte. Main pump with 3-ph AC motor and inverter provide setting electrolyte flow rate with help of ultrasonic flowmeter. Another magnetic pump used for draining electrolyte form storing tank to main supplying tank through filters. Output of power supply is 30 volt and 100 ampere.



Fig. 1 The ECM machine.

2.2. Materials and measurements

Fig. 2 displays workpiece and tool with their fixtures in the machining chamber. Thirty-one 321stainless steel bars 8 mm in diameter specimens were used as workpiece for runs and Table 1 presents the weight percentage of chemical composition for the workpiece material. Commercial cylindrical copper with the same diameter as workpiece were also employed as tool. As long as experiments conducted in stable conditions and with uniform initial gap distance, workpiece and tool were grinded and deburred to remove any possible surface irregularities to guarantee an even and parallel surfaces.

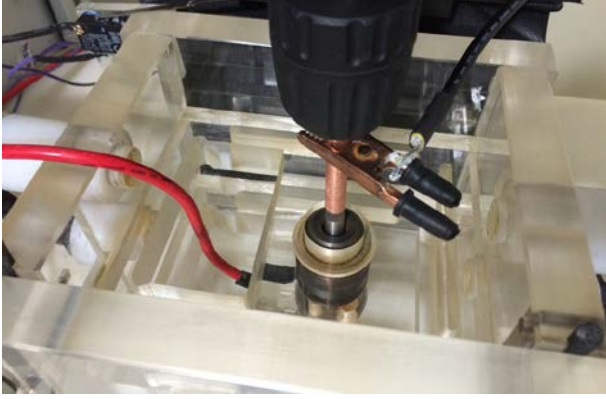


Fig. 2 machining chamber with workpiece and tool.

The experiments were carried out in NaNO₃ solution electrolyte with various concentrations. The electrolyte flow system used in cross and planning method to ensure an effective flushing during machining. The weight of workpiece was measured before and after machining by a precision weighing machine (0.0001g) for calculating the material removal rate (MRR). The arithmetic mean roughness (Ra) was employed to evaluate surface roughness of specimens. This measurement was performed with the help of surface tester SJ-210-MITUTOYO. The cut-off length and measuring speed were set as 0.8 mm and 0.5mm/s respectively.

Table 1: Chemical composition (%wt) of the 321 stainless steel

Fe	C	Mn	Si	S	P
Rem	0.045	1.66	0.479	0.014	0.034
Cr	Ni	Cu	Mo	Co	Ti
18.05	8.81	0.59	0.64	0.169	0.227

3. Design of experiments (DOE)

3.1. Experimental plan and conditions

The machining was carried out for a fixed time interval of 2 min and an initial gap distance was 0.6 mm. In the present study, the experimentation strategy was considered based on central composite second order rotatable design (CCD) for the purpose that the higher-order input parameters effects and their interactions on machining responses were determined. The values of four process inputs and their levels are shown in Table 2. Therefore, the design consists of 31 runs, in which 16 factorial points, 8 axial points, 7 center points for estimating the experimental error and the central composite parameter α was considered 2 to ensure a rotatable design Table 3 presents the values of machining responses, i.e. MRR and Ra according to experimentation plan with various sets of machining parameters, i.e. voltage (x_1), tool feed rate (x_2), electrolyte flow rate (x_3) and electrolyte concentration (x_4).

3.2. Response Surface Methodology (RSM)

In this research, Response Surface Methodology (RSM) was applied, as one of DOE methods, for determining how the machining parameters influence machining responses. RSM is a powerful way for building the relationship between machining

parameters and responses that are useful for the modeling and analysis of the problems; accordingly, the relationship mathematically and statistically could be developed by second-order polynomial as follows:

$$y = b_0 + \sum_i^k b_i x_i + \sum_i^k b_{ii} x_i^2 + \sum_i \sum_j b_{ij} x_i x_j + \varepsilon \quad (1)$$

Where y is the desired response, e.g. MRR and Ra in this paper, x_i is the uncoded or coded levels of the independent variables, and ε is the fitting error. Also, the coefficient b_0 is the constant value or intercept and the coefficients b_i , b_{ii} and b_{ij} represent the linear, quadratic and interaction terms respectively (Myers and Montgomery, 1995).

Table 2: The independent ECM process factors and their levels

Factors	Symbol	Unit	Levels				
			-2	-1	0	1	2
Voltage	x_1	V	10	15	20	25	30
Tool feed rate	x_2	mm/min	0.2	0.3	0.4	0.5	0.6
Electrolyte flow rate	x_3	l/min	5	6	7	8	9
Electrolyte concentration	x_4	g/l	50	100	150	200	250

4. Design of experiments (DOE) Validation and analysis of models

Adequate and suitable measures, tests and analyses were examined the models, so the fitness of the models to the experimental data, significant and insignificant parameters and adequacy of models were analyzed; that is, the analysis of variance (ANOVA) and the F-ratio test have been executed to check the goodness of the mathematically modeled fittings. Moreover, the R-squared (R-Sq) and adjusted R-squared (R-Sq(adj)) is used for assessing the modeling goodness of fit, as more the R² approaches unity, the better the model fits the experimental data. Indeed, the best condition of analysis of effective models happens as the lack-of-fit is insignificant. Then, a student's t-test has also been performed for determining the significance of each parameter in the models. Accordingly, insignificant terms have been eliminated from the models, and ANOVA has been done again through the available significant terms. In addition, a complete residual analysis has been done through normal probability plot of residuals, plot of residuals versus fitted values and plot of residuals against the order of experimentations in order that the quality of fit for the responses and adequacy of models have been examined.

5. Results and discussion

5.1. Mathematical modeling of MRR

According to the model explained by Eq. 1, Table 4 details the ANOVA and F-ratio test information about MRR response. On the grounds that the p-value of the quadratic model is greatly less than 0.05, the model is statistically significant in the 95% of confidence interval. Besides, the p-value of the lack-of-fit is more than 0.05, so this term is insignificant which is desired. Through the ANOVA result, the MRR model is developed with coded variables as follows:

$$\begin{aligned} MRR = & -0.3374 + 0.0055x_1 - 0.0496x_2 + 0.0755x_3 + 0.00072x_4 \\ & - 1.4494E - 05x_1^2 + 0.2275x_2^2 - 0.00551x_3^2 - 2.50494E - 06x_4^2 \\ & + 0.00049x_1x_2 + 5.875E - 05x_1x_3 + 3.4875E - 05x_1x_4 + 0.0073x_2x_3 \\ & - 2.0875E - 04x_2x_4 + 9.125E - 06x_3x_4 \end{aligned} \quad (2)$$

The R² (R-Sq) and adjusted R² (R-Sq(adj)) are respectively 99.45% and 99.25% for the above MRR model which ensuring an excellent fitting for the model.

Table 3: Central composite design plan matrix and results

Exp No.	Factors				Responses	
	x ₁	x ₂	x ₃	x ₄	MRR (g/min)	Ra(μm)
1	-1	-1	-1	-1	0.1253	0.76
2	1	-1	-1	-1	0.2134	1.08
3	-1	1	-1	-1	0.1547	0.89
4	1	1	-1	-1	0.2361	1.13
5	-1	-1	1	-1	0.1246	0.84
6	1	-1	1	-1	0.2107	1.16
7	-1	1	1	-1	0.1569	0.96
8	1	1	1	-1	0.2525	1.31
9	-1	-1	-1	1	0.1673	1.29
10	1	-1	-1	1	0.2921	1.94
11	-1	1	-1	1	0.1975	1.63
12	1	1	-1	1	0.3218	2.21
13	-1	-1	1	1	0.1779	1.47
14	1	-1	1	1	0.2979	2.15
15	-1	1	1	1	0.2019	1.78
16	1	1	1	1	0.3235	2.49
17	-2	0	0	0	0.1154	1.22
18	2	0	0	0	0.3379	2.17
19	0	-2	0	0	0.1989	1.12
20	0	2	0	0	0.2755	1.51
21	0	0	-2	0	0.1927	1.12
22	0	0	2	0	0.2194	1.35
23	0	0	0	-2	0.1365	0.72
24	0	0	0	2	0.2696	2.45
25	0	0	0	0	0.2351	1.00
26	0	0	0	0	0.2291	0.98
27	0	0	0	0	0.2250	1.02
28	0	0	0	0	0.2238	0.96
29	0	0	0	0	0.2220	1.04
30	0	0	0	0	0.2275	0.95
31	0	0	0	0	0.2232	1.02

Table 4: The ANOVA results for MRR response using the Minitab software

Source of variation	DF	Sum of Squares	Mean Squares	F value	P value
Regression	14	0.103873	0.007419	219.16	0.000
Linear	4	0.100478	0.025120	742.00	0.000
Square	4	0.002148	0.000537	15.85	0.000
Interaction	6	0.001216	0.000208	6.14	0.002
Residual Error	16	0.000542	0.000034		
Lack-of-Fit	10	0.000419	0.000042	2.06	0.195
Pure Error	6	0.000122	0.000020		
Total	30	0.104414			
R-Sq = 99.45%, R-Sq(adj) = 99.25%					

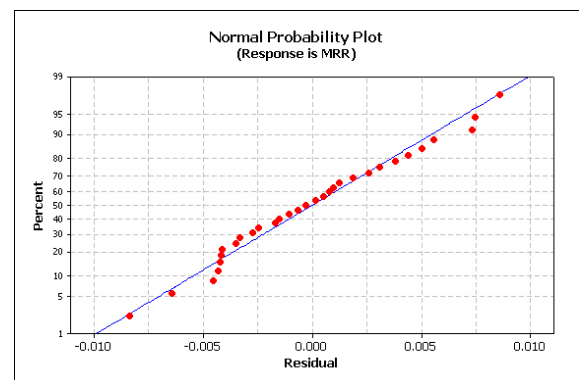
A student's t-test has also been performed for determination of significant terms in the model. Based on the t values and their p values shown in Table 5, it is concluded that all the linear terms (input parameters, i.e. x₁: voltage, x₂: feed rate, x₃: flow rate and x₄: electrolyte concentration), quadratic terms of input factors x₂, x₃ and x₄, and interaction effect of factors x₁ and x₄ are significant and other terms are insignificant. The insignificant terms have been eliminated, and the ANOVA has again been done to significant terms. As a result, the final reduced model of MRR based on significant parameters in terms of coded factors is developed as follows:

$$MRR = -0.35879 + 0.00549x_1 - 0.02305x_2 + 0.08043x_3 + 0.00069x_4 + 0.23137x_2^2 - 0.00547x_3^3 - 2.48952E-06x_4^4 + 3.48750E-05x_1x_4 \quad (3)$$

Table 5: The T-test results for MRR response including all parameters using the Minitab software

All Term	Coefficient	SE coefficient	T value	P-value
x ₁	0.053621	0.001188	45.148	0.000
x ₂	0.016204	0.001188	13.644	0.000
x ₃	0.003796	0.001188	3.196	0.006
x ₄	0.032163	0.001188	27.080	0.000
x ₁ * x ₁	-0.000362	0.001188	-0.333	0.743
x ₂ * x ₂	0.002275	0.001188	2.091	0.053
x ₃ * x ₃	-0.005512	0.001188	-5.066	0.000
x ₄ * x ₄	-0.006262	0.001188	-5.755	0.000
x ₁ * x ₂	0.000244	0.001455	0.168	0.869
x ₁ * x ₃	0.000294	0.001455	0.202	0.843
x ₁ * x ₄	0.008719	0.001455	5.994	0.000
x ₂ * x ₃	0.000731	0.001455	0.503	0.622
x ₂ * x ₄	-0.001044	0.001455	-0.718	0.483
x ₃ * x ₄	0.000456	0.001455	0.314	0.758

Next, a complete residual analysis has been performed for evaluating the quality of fit for the yielded MRR response. Normal probability plot of residuals in Fig. 3 shows that experimental data are located approximately along a straight line; that is, the experimental values correlate closely with the predicted values for the response.

**Fig. 3** Normal probability plot of Residuals for MRR

The plot of residuals versus fitted values is shown in Fig. 4 indicates that only small variations can be seen. Also, it is clearly observed from the plot of residual versus order of the experimentation, Fig. 5, that residuals are independent of one another and both negative and positive residuals exist in this plot indicate no special tendency. Hence, the presented discussion implies that the above MRR model does not show any inadequacy.

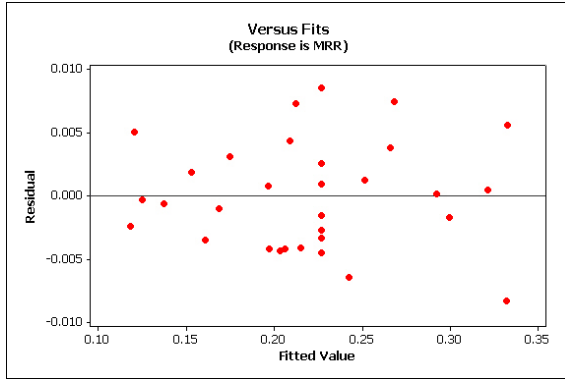


Fig. 4 Residuals versus Fits for MRR

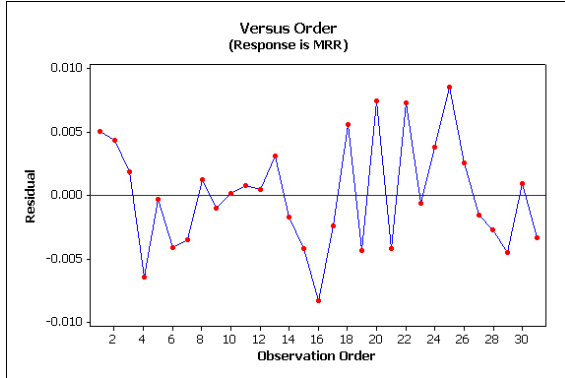


Fig. 5 Residuals versus Observation Order for MRR

5.2. Mathematical modeling of Ra

The same procedure is used to deal with the Ra and the ANOVA details of quadratic model are shown in Table 6. The results of the table points out that the model is significant and the lack-of-fit is insignificant according to the p-values. Based on the ANOVA result, the developed mathematical model for Ra with coded variables as follows:

$$Ra = 8.75714 - 0.29921x_1 - 7.01905x_2 - 0.91042x_3 - 0.0234x_4 + 0.0069x_1^2 + 7.74256x_2^2 + 0.05743x_3^2 + 5.79702x_4^2 - 0.01125x_1x_2 + 0.00338x_1x_3 + 0.00035x_1x_4 + 0.08125x_2x_3 + 0.01013x_2x_4 + 0.00051x_3x_4 \quad (4)$$

Table 6: The ANOVA results for Ra response using the Minitab software

Source of variation	DF	Sum of Squares	Mean Squares	F value	P Value
Regression	14	7.73831	0.55274	648.07	0.000
Linear	4	6.16678	1.54170	1807.59	0.000
Square	4	1.39314	0.34828	408.35	0.000
Interaction	6	0.17839	0.02973	34.86	0.000
Residual Error	16	0.01365	0.00085		
Lack-of-Fit	10	0.00688	0.00069	0.61	0.767
Pure Error	6	0.00677	0.00113		
Total	30	7.75195			

The R² and adjusted-R² for the Ra trimmed model are respectively 99.82% and 99.67% revealing sufficient adequacy in model predictive capabilities.

The student's t-test has also been done for determining the significance of each parameter. The results in Table 7 indicates that all linear and quadratic terms of parameters and the interaction between x_1 (voltage) and x_3 (flow rate), x_1 and x_4 (concentration), x_2 (tool feed rate) and x_4 , and x_3 and x_4 are significant. The other

model terms can be regarded as insignificant terms. By removing these insignificant terms and applying the ANOVA, the proper quadratic model for Ra can be developed as follows:

$$Ra = 8.61964 - 0.303714x_1 - 6.6753x_2 - 0.87792x_3 - 0.0234x_4 + 0.0069x_1^2 + 7.74256x_2^2 + 0.05743x_3^2 + 5.79702x_4^2 + 0.00338x_1x_3 + 0.00035x_1x_4 + 0.01013x_2x_4 + 0.00051x_3x_4 \quad (5)$$

Table 7: The T-test results for Ra response including all parameters using the Minitab software

All Term	Coefficient	SE coefficient	T value	P-value
x_1	0.239583	0.005961	40.190	0.000
x_2	0.103750	0.005961	17.404	0.000
x_3	0.070417	0.005961	11.812	0.000
x_4	0.428750	0.005961	71.922	0.000
$x_1 * x_1$	0.172426	0.005461	31.572	0.000
$x_2 * x_2$	0.077426	0.005461	14.177	0.000
$x_3 * x_3$	0.057426	0.005461	10.515	0.000
$x_4 * x_4$	0.144926	0.005461	26.537	0.000
$x_1 * x_2$	-0.005625	0.007301	-0.770	0.452
$x_1 * x_3$	0.016875	0.007301	2.311	0.034
$x_1 * x_4$	0.086875	0.007301	11.899	0.000
$x_2 * x_3$	0.008125	0.007301	1.113	0.282
$x_2 * x_4$	0.050625	0.007301	6.934	0.000
$x_3 * x_4$	0.025625	0.007301	3.510	0.003

Like before, a complete residual analysis has been done presented in the Figs. 6, 7 and 8. Similarly, the Ra model does not show any inadequacy.

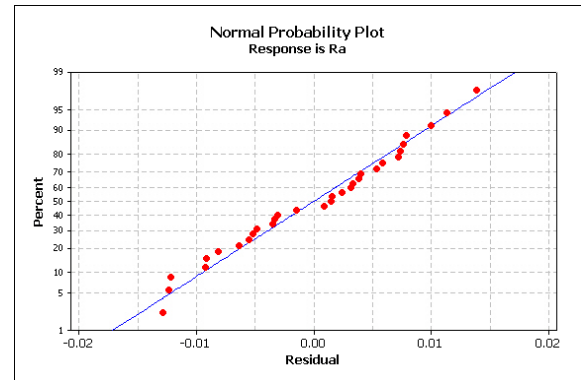


Fig. 6 Normal probability plot of Residuals for Ra

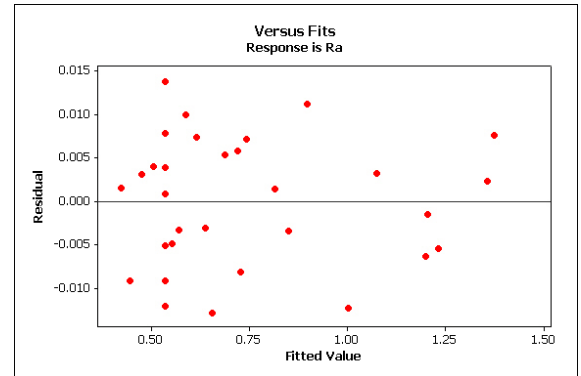


Fig. 7 Residuals versus Fits for Ra

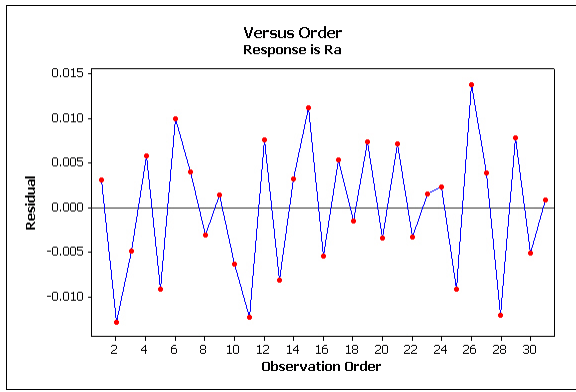


Fig. 8 Residuals versus Observation Order for Ra

5.3. Optimization by desirability functions

This desirability function approach developed by Derringer and Suich [16] is an attractive search-based optimization technique used to find the optimal parameters combination globally. This technique uses a desirability function as an objective function in which each response y_i is transformed to an individual desirability function (d_i) between zero and one. That is, one indicates that the response is the completely desirable value (at its target), and zero shows that the response is the least desirable value (outside of its acceptable limits). Thus, the overall (composite) desirability (D) is determined by the geometric mean of the individual desirability functions as follows:

$$D = (d_1 d_2 \dots d_n)^{1/n} = \left[\prod_{i=1}^n (d_i) \right]^{1/n} \quad (6)$$

Where n is the number of responses. Also, the individual desirability function d_i will be defined depending on whether the response y_i is to be maximized, minimized, or assigned a target value.

The goal of optimization in this article is to find maximum MRR (productivity) and minimum surface roughness (R_a). The optimization results were obtained by Minitab 16 software. According to the results of optimization, 30 V voltage, 0.6 mm/min tool feed rate, 7.34 l/min electrolyte flow rate, and 250 g/l concentration is the optimal machining parameters setting for achieving maximum MRR. Similarly, 18.28 V voltage, 0.38 mm/min tool feed rate, 6.74 l/min electrolyte flow rate, and 84.34 g/l concentration is the optimal machining parameters combination for achieving minimum R_a .

6. Conclusion

This study highlights that the electrochemical machining of 321 stainless steel criteria, i.e. MRR and R_a are greatly influenced by the different machining parameters. To sum up, the followings can be acquired from this investigation as main findings:

1. For gaining the model that covers all linear, quadratic and interaction terms, the RSM method has been appointed properly as the DOE method for solving curvature in ECM process responses.
2. Mathematical models have been developed through the RSM method for correlation the machining parameters, i.e. voltage, tool feed rate, electrolyte flow rate and concentration on the machining criteria, i.e. MRR and R_a , of 321stainless steel.
3. According to the ANOVA among the process parameters, the machining voltage and electrolyte concentration are the most effective factors on the machining criteria.
4. Increasing voltage and electrolyte concentration lead to increase in the MRR. Also, the proper flushing of electrolyte improves MRR which can be regulated by the electrolyte flow rate.

5. According to the optimization results, 30 V voltage, 0.6 mm/min tool feed rate, 7.34 l/min electrolyte flow rate, and 250 g/l concentration is the optimal machining parameters setting for maximum MRR, and 18.28 V voltage, 0.38 mm/min tool feed rate, 6.74 l/min electrolyte flow rate, and 84.34 g/l concentration is minimum R_a .

7. Acknowledgment

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HOOP TENSILE PROPERTIES OF FILAMENT WOUND PIPES

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Abstract: In this study hoop tensile properties of continuous fiber reinforced composites pipes are investigated. The test pipes were manufactured of glass fiber and epoxy resin by filament winding method with three different winding angle configurations (10°, 45° and 90°). Three specimens from each model of filament wound pipes with help of split-disk tests were tested and the hoop tensile strengths and modulus of elasticity were determined. From received results it is concluded that, mechanical properties of composite specimens are depended from winding angles in filament winding technology, whereas that bigger winding angle lead to higher hoop tensile properties of filament-wound tubular samples. The optimal values for the hoop tensile strength are obtained for the samples winded with 45° winding angle.

KEYWORDS: COMPOSITE PIPES, FILAMENT WINDING, SPLIT-DISK TEST, GLASS FIBERS, EPOXY RESIN

1. Introduction

Many of the modern industrial applications and technologies require materials with superior properties that cannot be met by conventional monolithic materials, such as metal alloys, ceramics and polymers. Because of their heterogeneous nature composite materials have several advantages over traditional engineering materials, which make them attractive for many industrial applications. Properties of composites arise as a function of its constituent materials, their distribution, and the interaction among them and as a result an unusual combination of material properties can be obtained. Composite materials have superior mechanical properties like high specific stiffness, high specific strength, high fatigue strength and good impact properties.

From the wide family of composites, fiber reinforced composites have taken much attention due to their better mechanical properties. Composites produced by long fibers with high aspect ratio are called continuous fiber reinforced composites. Fibers are the materials with very high aspect ratios; i.e. they have one very long dimension compared to the others. They have significantly more strength in the long direction than the other directions. These composites have found a wide range of application area due to their anisotropic nature, the direction dependence of their properties results in much better design flexibility that cannot be obtained by monolithic materials or particle reinforced composites.

Filament winding technique can be accepted as one of the most common production techniques, for the synthesis of polymer matrix composites (PMC).

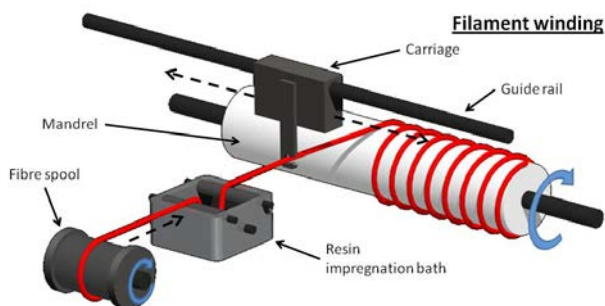


Figure 1. Schematic presentation of the filament winding technology

Filament winding is a process where the reinforcing agent in the form of continuous fibers (glass, carbon, aramid, etc.) is accurately positioned in the impregnation agent in the form of liquid resin (polyester, epoxy, etc.) to form a cylindrical shape. Figure 1 shows a filament winding process. A number of fiber

rovings are pulled from a series of creels and tensioners that control the tension of the fibers into a liquid resin bath that contains the resin itself, the hardeners and the accelerators. At the end of the resin tank, the rovings are pulled through a wiping device where the excess resin is removed from the rovings. Once the rovings are thoroughly impregnated and wiped, they are collected together in a flat band, pass through the carriage and located on the mandrel. The traversing speed of carriage and the winding speed of the mandrel are controlled to generate the desired winding angle patterns. After the appropriate number of layers has been applied, curing is carried out in an oven or at room temperature, after which the mandrel is removed.

The filament winding method in general, has several advantages over other methods.

- It is highly repetitive and precise in fiber placement.
- It can use continuous fibers to cover the whole component area, which simplifies the fabrication process of many components and increases reliability and lowers the cost by reducing the number of joints.
- It is less labor intensive, which reduces the costs significantly.
- Large and thick walled structures can be built.

Based on that, it is clear that the filament winding technology is used for creating new materials with distinct anisotropy according to the direction in which the fiber is placed. In other words, different directions result in a material with different mechanical properties.

Three types of testing geometry are commonly used in testing of filament-wound composite structures, namely; flat specimens (coupon specimens), ring specimens, and tubular specimens. Axial (tension/compression), shear, and bending response of each testing geometry can be determined by applying a suitable loading to the specimen. For evaluation of the tensile properties of filament wound composite structures split-disk test is usually used.

Proposed ring shape of samples may be applied in axial tension test, internal pressure test, etc., as well as their combinations. Hoop tensile strength of specimens can be determined with help of split-disk test. Split-disk tests are very efficient in determine the performance of tubular structures which are usually used under internal pressure developing high hoop.

This research will present the hoop tensile properties of different models of specimens based on the different winding angle, manufactured with conventional filament winding equipment.

2. Preconditions and means for resolving the problem

a. Experimental stand

Samples with different winding designs were wound on iron mandrel with help of laboratory filament winding machine MAW FB 6/1 with six axes, roller type resin bath manufactured from Mikrosam A.D. The filament winding machine is given in Figure 2.



Figure 2. Filament winding machine MAW FB 6/1

The resin system employed in the fabrication of the pipes is Araldite LY564/Aradur 917/Accelerator 960-1 from Huntsman. This polymer system is suitable for filament winding, wet laminating, and pultrusion processes and it was recommended by the producer. The reinforcements employed in the fabrication of the pipes are 10 bobbins of E- glass fiber roving 185P with 1200 tex from Owens Corning. Glass fibers with constant fiber tension 110 N pass through a resin bath and gets wet before winding operation. The velocity of the filament winding was 21 m/min. During the manufacturing of the test pipes, three different winding angles are used, 10°, 45° and 90° (table 1).

Table 1: Designation of models of samples

Number of samples	Characteristics (conditions of the experiment)		
	X ₁ (m/min) velocity of the filament winding	X ₂ (N) fiber tension	X ₃ (°) winding angle
1	21	110	10
2	21	110	45
3	21	110	90

Winding angle is the angle between fiber and the line on surface of the mandrel, which is parallel to mandrel axis. Coupled helical winding of layers ($\pm \theta$) are usually preferred, whereas hoop winding - winding angle, very close to 90° and winding with very low winding angle can also be used. By varying the winding angle with respect to the mandrel axis, directional strength can be obtained by

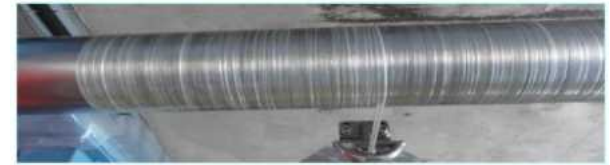
considering the loads, which will operate on the finished product.



low winding angle ($\theta = 10^\circ$)



helical winding ($\theta = 45^\circ$)



hoop winding ($\theta = 90^\circ$)

Figure 3. Winding of impregnated glass fibers

Calculated mass ratio between fiber and resin of the produced composite pipes was 75:25 wt. %. After winding samples were cured with industrial heater at 80°C and at 140°C, for four hours. After the curing operation, the removal of the mandrel from the specimens was performed. In this experimental study the investigation of the effect of winding angles on hoop tensile strength of glass fiber reinforced filament wound ring specimens was performed.

3. Results and discussion

For tensile tests three split-disk test specimens from each model of filament wound pipes was cut according to ASTM D2290. Tensile tests of split-disk samples were carried out at room temperature using universal testing machine Schenck with max load of 250 kN and loading speed of 5 mm/min. Width and thickness of each split-disk samples was measured with help of micrometer with reading to at least 0.0254mm. In this way prepared specimens were elongated till rupture with help of test fixture, made according to standard (Fig. 4).



Figure 4. Split-disk test specimen and test fixture with specimen for hoop tensile testing

Based on the obtained results, the general behavior of the specimens were determined. The results of the testing method of the split-ring specimens for determination of the hoop tensile strength are presented in Table 2.

Table 2: Hoop tensile strength results of split-disk tests

	Sample Designation	Weight (g)	Width (mm)	Thickness (mm)	F_{max} (N)	Tensile strength (MPa)	Winding angle (°)
1	1-1	42,2	13,97	3,18	1600	18,00	10
	1-2	43,0	13,85	3,14	1250	14,34	
	1-3	43,7	14,00	3,14	1759	20,00	
2	2-1	53,6	14,01	3,18	25000	280,57	45
	2-2	53,8	13,9	3,16	24225	275,76	
	2-3	53,8	14,01	3,16	24400	275,57	
3	3-1	52,8	14,06	3,64	94500	923,24	90
	3-2	52,8	14,12	3,64	90250	877,97	
	3-3	53,8	14,12	3,65	93000	902,25	

The hoop tensile strength of the specimens were calculated by using the following equation:

$$\sigma = \frac{F_{max}}{2 \cdot A_m} \quad (1)$$

In equation (1) σ is ultimate hoop tensile strength, MPa, F_{max} is maximum load prior to failure recorded in Newton (N), whereas A_m is minimum cross-sectional area of the two reduced sections, $d \times b$, mm² (Fig. 5).

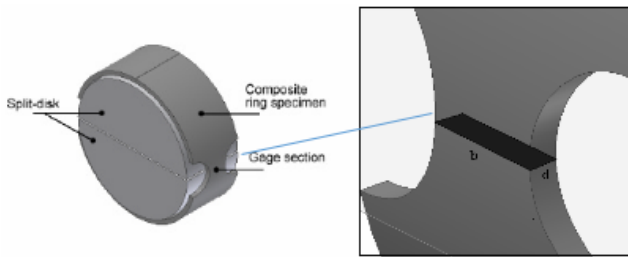


Figure 5. Cross-sectional area on which hoop tensile stress is applied

From the results shown in table 2 can be observed, that split-disk specimen 3 with tensile strength with average value of 901,15MPa had shown the best results and it was wound with angle 90°. The specimen designated with 1 wound with angle 10° had shown much lower value up to 10 times lower than tensile strength from sample 3. From received results it can be concluded that mechanical properties of composite specimens depended from winding angles in filament winding technology, namely, the bigger winding angle lead to higher hoop tensile properties of filament-wound tubular samples. The optimal values for the hoop tensile strength are obtained for the samples wound with 45° winding angle.

4. Conclusion

Advantages of filament winding technique are high specific strength, specific modulus and fiber volume percentage of the finished products and high repeatability

of the process. Production can be repeated successively, to obtain the same properties of the finished products.

The main limitation of filament winding technique is the difficulty in production of complex shapes due to the requirement of very complex mandrel designs. From results of the mechanical testing can be concluded, that the best results in tensile strength and break force were obtained from composite pipes winding with angle 90°. Change of winding angle will cause variation in the final mechanical results, whereas that bigger winding angle lead to higher hoop tensile properties of filament-wound tubular samples.

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QUALIMETRIC PRINCIPLES OF ASSESSMENT OF REINFORCED STEEL

КВАЛИМЕТРИЧЕСКИЕ ПРИНЦИПЫ ОЦЕНКИ АРМАТУРНОГО ПРОКАТА

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Abstract: The paper considers the issues of qualimetric assessment of quality of reinforced steel. The dependences of the rate group of the mechanical properties from room profile. Built a regression equation characterizing the effects of deformation processing on the quality of rebar.

KEY WORDS: QUALIMETRIC ESTIMATION, REINFORCED STEEL, QUALITY INDICATORS, REGRESSION EQUATION.

Introduction

The company JSC "ArcelorMittal Temirtau" is constantly working on improvement of the existing technologies, the development and implementation of new technologies aimed at expanding the range of shape rolling mill and improved the quality of steel products. To improve the quality of reinforced steel, analysis of geometry, reducing the number of defects arises the proposed activities of authors [1-4].

Compliance quality calibrated with the requirements of state standards for delivery, and assessment of the stability characteristics of the control material can be confirmed using the principles of quantitative assessment of product quality (principles of qualimetry) [5].

Qualimetry – a scientific field that combines quantitative methods of assessing the quality of various objects [6]. Qualimetric assessment of the quality allows you to comprehensively assess the quality of the product a single numeric indicator at the same time on all its properties.

Thus, the aim of this work is qualitative quality assessment integrated assessment of the quality of long products depending on different modes of deformation processing.

The objective is achieved by solving the following problems:

- 1) rationale for the range of indicators characterizing the quality of products and services;
- 2) choice of a technique of definition of indicators of quality of objects;
- 3) compilation of quality indicators;
- 2) build of quality equations and its analysis [7].

Methodology of study

Summing up the requirements at the present time the quality of shape metal, on the basis of qualimetry methods to construct a hierarchical set of properties [6], using, for example, tabular form, wood properties (table 1) recommended [7].

Table 1 – Hierarchical set of properties of reinforcing bars

i=0	i=1	i=2	i=3	i=4
Quality of the calibrated metal	Quality of metal	Chemical analysis	Content of chemical elements on the ladle analysis	C, %
				Mn, %
				Si, %
		Mechanical properties	Stretching	σ_T , MPa
				σ_B , MPa
				δ , %

The main method of assessing the level of quality used in this work is differential. According to the author [6], the most appropriate differential assessment of the quality of steel products will be the probability of satisfying the requirements of the standard.

According to accepted designations in the work, differential assessment of the quality of the shape rolled metal the equal probability in the interval by the formula for upper bounds:

$$k_{ij} = P(r_{ij}^{\min} \leq r_{ij} \leq r_{ij}^{\max}) = F(r_{ij}^{\max}) - F(r_{ij}^{\min}), \quad (1)$$

where $F(r_{ij}^{\max})$ and $F(r_{ij}^{\min})$ – values of the distribution of cumulative function in the points $(r_{ij}^{\max})$ and $(r_{ij}^{\min})$.

For the case of normal distribution, this dependence takes the form:

$$k = \Phi\left(\frac{r^{\max} - \bar{r}}{S}\right) - \Phi\left(\frac{r^{\min} - \bar{r}}{S}\right), \quad (2)$$

where Φ – Laplace function.

In accordance with the principles of qualimetry for each level of properties the weighting factors are assigned. First defined group coefficients, then, based on them, the weighting factors for each particular property [7]:

$$\sum \alpha'_i = \alpha'_{GR}, \quad (3)$$

where α'_i – weighting factor within the group of properties;

α'_{GR} – group (tier) weighting factor.

On each tier must comply with the condition:

$$\sum \alpha_i = 1, \quad (4)$$

where α_i – weighting factor $0 \leq \alpha_i < 1$.

Then we define a method of consolidating the assessments of individual properties to obtain a comprehensive measure of quality K_0 :

$$K_0 = \sum_{i=1}^n \alpha_i k_i, \quad (5)$$

where k_i – differential quality index; n – the number of quality indicators ($1 \leq j \leq n$).

It is theoretically possible that the low differential score on one indicator overlaps high, according to another indicator, i.e., a comprehensive assessment will be quite high, and the measured values r_{ij} will outside of $[r_{ij}^{\min}; r_{ij}^{\max}]$. To prevent such situations in

qualimetry apply the condition for the vanishing of a comprehensive assessment under certain conditions. This technique is called the "coefficient of veto". The coefficient of veto W is used as a cofactor and has only two values: either 1 or 0.

In case of double-sided border:

$$W_i = \begin{cases} 1, & \text{if } r_{ij}^{\min} \leq r \text{ and } r \leq r_{ij}^{\max}; \\ 0, & \text{if } r_{ij}^{\min} > r \text{ or } r > r_{ij}^{\max}; \end{cases}$$

$$W_i = \begin{cases} 1, & \text{if } r_{ij}^{\min} \leq r; \\ 0, & \text{if } r_{ij}^{\min} > r. \end{cases}$$

Condition treatment K_0 to zero it is necessary to check for each single quality indicator.

Thus, in the period from January to March 2013 to assess the quality of rebar rebars 10 mm; 12 mm; 14 mm; 16 mm; 18 mm; 20 mm; 22mm; 25mm; 32mm used the technique of the authors [7,8].

As indicators of the quality of rebar, used chemical composition of the steel according to the content of essential elements in % – carbon (C) manganese (Mn), silicon (Si) and mechanical properties of rebar – yield strength (σ_T , MPa), tensile strength (σ_B , MPa), relative elongation (δ , %).

For each quality indicator a complete statistical analysis of sample data [9]. Integrated assessment of the quality of rebars used data from acceptance tests after rolling them on a continuous 16-stand medium section mill in terms of JSC "ArcelorMittal Temirtau" in the study period. The material is all covered in the sample profiles - steel grade 5sp.

In accordance with the adopted methodology, the weighting factors are evenly distributed on the generated table 1 tree of properties in accordance with condition [7].

According to the single properties of the samples calculated differential quality indicators on the example of profile №14: $k_C = 0,7930$; $k_{Mn} = 0,9999$; $k_C = 0,8981$; $k_{\sigma_T} = 0,9019$; $k_{\sigma_B} = 0,7821$; $k_\delta = 0,9188$.

Results and discussion

In Fig. 1 shows the calculated integrated values of indicators on the quality of the chemical properties and the quality of mechanical properties of different numbers of profiles. From Fig.1 shows that a more stable quality have average profile numbers № 16÷№ 18. Lowest quality in the profile № 12, equal to 0,81. The other numbers are the profiles show a very good level of quality is approximately 0.90.

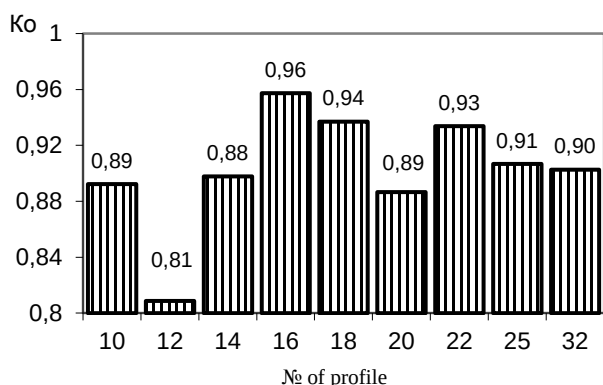


Fig. 1 – Integrated indicators of quality of different profiles of calibrated rolled metal

Comprehensive assessment of the quality of rebar № 16 showed a good level – 0,96 that, given the existing lack of influence of the content in the sample of the chemical elements, says about a certain factor, having an influence on the magnitude of the mechanical characteristics of the profile [10]. Likely is a particular mode of deformation processing of this profile that, when well-functioning of the mill provides a stable level of quality, at a somewhat higher ductility and a lower deformation resistance, compared with the adjacent profiles.

To study the effects of deformation processing on the quality profile used data on the quality of mechanical properties, because the quality of the chemical composition is laid in steel melting and deformation modes of processing cannot influence.

Quality indicators of the mechanical properties of various calibrated rolled metal profiles are shown in Fig. 2.

To predict the mechanical properties, in accordance with the recommendations of [10], on the same data the authors calculated the effect on the quality indicator of the mechanical properties of the number of rebar H. Obtained regression equation:

$$K_{mech} = 0,7573 + 0,0463H - 0,0036H^2; R^2 = 0,24. \quad (6)$$

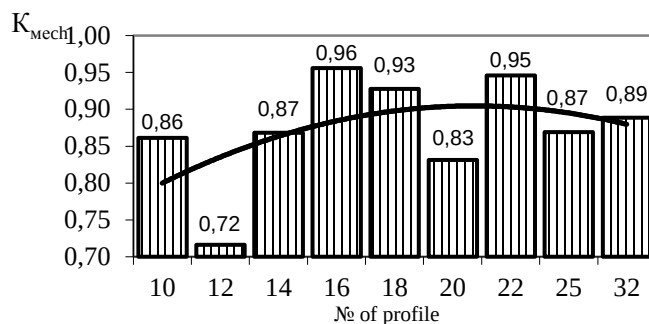


Fig. 2 – Quality indicators of mechanical properties of different profiles of calibrated rolled metal

The obtained equation is shown in Fig. 2 as line. From the regression equation follows the weak impact of profile number on the quality of mechanical properties. The histogram shows significant fluctuations in the level of quality of mechanical properties, the value of 0.72 in profile № 12 to the maximum value, equal to 0.96, corresponding to the profile number 16.

Moreover, the fluctuations in the values of quality repeat those have integrated quality indicator K_o , indicating the likely influence of deformation processing or other unaccounted factors on the values of the integrated indicator of quality.

To determine the effect of the quality of the chemical properties of the constructed histogram group of quality indicators of the chemical composition of different numbers of profiles (Fig. 3).

The histogram is also showing typical variations in the quality of the chemical properties, but to a much smaller range of $0,90 \div 0,96$, compared with the variation in mechanical properties ($0,72 \div 0,96$), which also confirms the relationship of the influence of chemical composition on the mechanical properties.

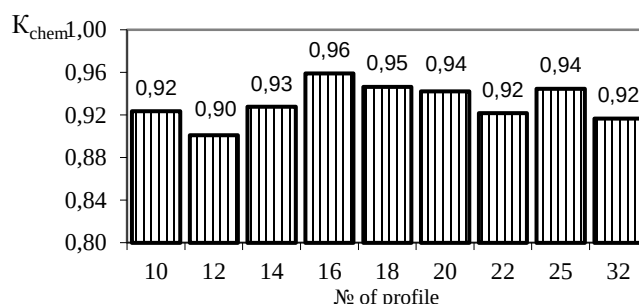


Fig. 3 – Quality indicators of chemical properties of different numbers of profiles of calibrated rolled metal

Graphical interpretation of dependence of K_{mech} and K_{chem} is shown at Fig. 4.

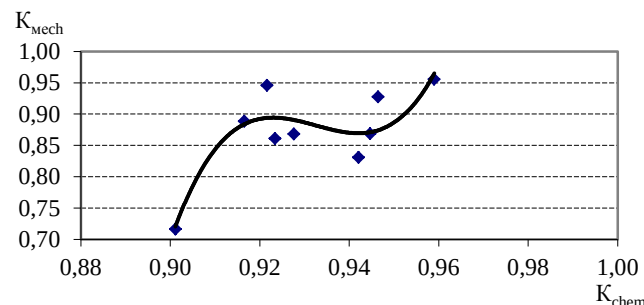


Fig. 4 – Dependence of the quality indicators of the mechanical properties from the values of chemical properties

The dependence was approximated by a polynomial of the third degree:

$$K_{mech} = -7251,2 K_{chem}^3 - 20285 K_{chem}^2 + 18914 K_{chem} - 5876,9. \quad (7)$$

The equation obtained is shown in Fig. 4 as line. The coefficient

of determination equal to $R^2 = 0.79$, which indicates a good addition. It also shows the influence on the mechanical properties, in addition to chemical composition, and also modes of deformation processing, which is in good agreement with the theory and technology of rolling.

Removing from the calculation dramatically highlights the statistical processing of the values along profile № 12, we show the updated dependence in Fig. 5.

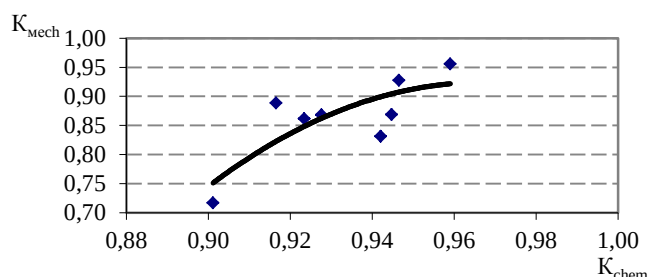


Fig. 5 – Updated dependence of the quality indicators of the mechanical properties from the values of chemical properties

The dependence was approximated by a polynomial of the second degree:

$$K_{mech} = -39,891 K_{chem}^2 + 77,149 K_{chem} - 36,378; R^2 = 0,64. \quad (8)$$

The equation obtained is shown in Fig. 5 as line. From the regression equation is shown a significant effect of the indicator of the chemical composition on the indicator of mechanical properties. Increasing the level of communication allows us to speak about the influence of deformation processing on the quality of the deleted profile № 12.

Conclusions

- 1) Defined the purpose and objectives of the qualitative evaluation of the quality of rebar, described the technique of study.
- 2) As indicators were selected: chemical composition of the steel in % – carbon (C) manganese (Mn), silicon (Si); mechanical properties – yield strength (σ_T , MPa), tensile strength (σ_B , MPa), relative elongation (δ , %).
- 3) Calculated differential (single), group and integrated indicators of quality. The overall quality appeared to be good within 0,81-0,96. Stable quality have profile numbers № 16 – № 18. Low quality profile № 12 is 0.81. The other profiles show a very good level of quality - 0,9÷0,94.
- 4) The dependences of the rate group of the mechanical properties from room profile. It is revealed that each profile number corresponds to the mode of deformation processing. The lower the profile, the greater the degree of deformation. The communication layer is insignificant ($R^2 = 0,24$).
- 5) In the dependences of K_{mech} from K_{chem} , revealed a high level of quality influence of chemical composition on the mechanical properties for all profiles № 10÷32 ($R^2 = 0,79$).
- 6) To study the effects of deformation processing on the quality of the constructed regression equation with the exception of calculation data profile № 12. The level of $R^2 = 0,64$ describes the influence of deformation processing on the quality of calibrated rolled metal.

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DEFECTS DETECTION IN GEAR USING DIRECT SPECTRUM ANALYSIS OF VIBRATION

ОБНАРУЖЕНИЕ ДЕФЕКТОВ В ЗУБЧАТОМ КОЛЕСЕ, ИСПОЛЬЗУЯ АНАЛИЗ ПРЯМОГО СПЕКТРА ВИБРАЦИИ

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Abstract: This article provides a way to detect fatigue cracks in welded gearwheel at reinforcement dimensional cutting mechanism (flying shears) of rolling mill by analyzing the direct spectrum of vibration. This method is progressive and allows through regular vibration measurements to assess equipment condition and predict performance.

Keywords: FLYING SHEARS, ROLLING MILL, MONITORING, DIRECT SPECTRUM, SENSOR, VIBRATION DIAGNOSTICS.

1. Introduction

Modern industry development produces the promoted requirements to reduction gearboxes reliability. Therefore on most industrial enterprises, possessing some park of gearboxes the vibration monitoring and diagnostics systems are implemented. Different firms can make these systems, which could have different configuration, but task for them one is looking after a working equipment, to expose the already present defects of gearing (basically gears, gearwheels, rolling bearings and journal bearings), and also to make the equipment capacity prediction. Machines and equipment condition monitoring is one of the most effective methods to decline accident rate and increase technical systems reliability. For the reduction gearboxes vibration monitoring is very important, because in the process of condition irreversible change there always is a chain of defects and even one of them really changes the equipment vibration background. The monitoring and diagnostics systems can be both stationary and portable. Functionally these systems do not differ practically. A difference is only in mobility. Application of these systems is gives another very important advantage: due to these systems, equipment repair conducted now on the real condition only. Using the monitoring and diagnostics systems could easy to detect fatigue cracks in welded gearwheel at reinforcement dimensional cutting mechanism (flying shears) of rolling mill by analyzing the direct spectrum of vibration. This method is progressive and allows through regular vibration measurements to assess equipment condition and predict performance.

2. Nature of gear's vibration

The most frequently used diagnostic parameters of parallel-shaft reduction gearbox is shown in Table 1. [1]

Table1.

Nr.	Type of defect	Diagnostic features	
		Vibration direct spectrum	Envelope spectrum of high frequency vibration
1	Pulsation of driving shaft	$f_{rot1}, kf_z \pm f_{rot1}$	$kf_{rot1}, k \leq 3$
2	Pulsation of driven shaft	$f_{rot2}, kf_z \pm f_{rot2}$	$kf_{rot2}, k \leq 3$
3	Distortion of driving gear	$2f_{rot1}, kf_z \pm 2f_{rot1}$	$2kf_{rot1}, k \leq 3$
4	Distortion of driven gear	$2f_{rot2}, kf_z \pm 2f_{rot2}$	$2kf_{rot2}, k \leq 3$
5	Teeth defect of driving gear	$kf_{rot1}, kf_z \pm kf_{rot1}$	$kf_{rot1}, k > 5$

6	Teeth defect of driven gear	$kf_{rot2}, kf_z \pm kf_{rot2}$	$kf_{rot2}, k > 5$
7	Tooth defect or tooth defect grease defect	kf_z	-
8	Defect of bearing	<i>RMS increasing (medium frequency MF)</i>	<i>the appearance of shock pulses on MF</i>
9	Bearing grease defect	<i>RMS increasing (UHF)</i>	<i>the appearance of shock pulses on UHF</i>

Note: f_{rot1} - rotating frequency of driving shaft, f_{rot2} - rotating frequency of driven shaft, f_z - tooth frequency, *RMS* - root mean square vibration, *MF* - medium frequency, *UHF* - ultra high frequency, $k=1,2,3,4,\dots$ [1]

3. Industrial vibration monitoring and diagnostics systems.

In world industry is used the enormous amount the rotating equipment vibration monitoring and diagnostics systems of different firms.

2.1. Stationary systems.

The stationary monitoring system is needed above all things for a multimode strength equipment, guided an auxiliary personnel. Exactly personnel errors is more frequent than all are the defects multiplying reason of the guided equipment, which it must find out practically instantly (for a few turns of rotor) for failure timely prevention.

On Figure 1 the simplified structure of the vibration monitoring and diagnostics stationary system is shown.

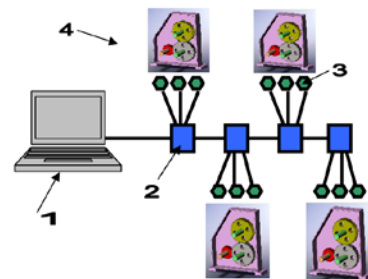


Figure1 Structure of the vibration monitoring and diagnostics stationary system.

1 - The computer with special software; 2 - The Signals transformation card in digital form; 3 - Vibration sensors; 4 - Supervising equipment.

2.2. Portable systems.

Equally with the stationary systems wide application is found the portable monitoring and diagnostics systems (Fig. 2), equipped by expert or automatic troubleshooting routines. These systems can be divided into two basic classes are the extended monitoring systems, including with the expert programs, it means, that diagnostics is executed by the prepared expert, and mass diagnostic systems with the standard rotating equipment automatic condition diagnostic and prediction programs. Such system consists of:

- A portable device (devices), providing vibration measuring and analysis in heavy industrial terms;
- Computer with the program of monitoring, containing a database and fulfilling operations row of signals analysis and processing of analysis results;
- Expert or automatic diagnostic program, processing obtained diagnostic information.



Figure 2. Vibration portable set on the vibration analyzer CД-21 base, produced by company BACT (Russia) [2]

4. Description of the equipment which was under control.

Method of fatigue cracks detection in welded gears and gearwheels with the help of the direct spectrum of vibration analysis can be applied in the study of all gears. This method has been tested on flying shear of steel plant's rolling mill.

Flying shears is a machine for cutting the continuous length rolled product that does not require a stop rolling. These shears (Fig.3) are composed of housing, a drive shaft with a driving gear (4) and the working shafts with the driven gear wheels (5 and 6) on which are mounted blades for cutting the reinforcement. Positions 1, 2 and 3 are places for vibration sensors mounting.

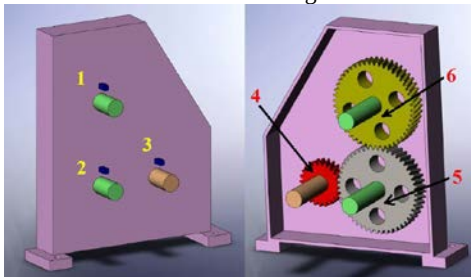


Figure 3. The scheme of flying shear under control.

For a complete research on the state of flying shears, it is necessary to organize the 6 points of vibration control (Fig.4).



Figure 4. The scheme of the 6 points of vibration control.

Reading data from the sensors is occurring remotely. To do this you must create a remote monitoring system (Fig.1)

The most effective way to monitor the status of welded gearwheels is direct spectra of vibration analysis, which is necessary to carry out about once a week.

5. The detection of a fatigue crack in a welded gear

Here is an example of the real detection of a fatigue crack in a welded gear. In comparison are given the spectrums: before appearance of cracks (black graph), when the crack has been formed (red graph) and after repair (blue graph) (Fig.5).

Since a crack formed in the top gearwheel, and the spectra are also obtained at the control point #5.

The direct spectrum (Fig.5), was obtained under the following conditions: measuring units: dB (A); cutoff frequency: $F_b = 800 \text{ Hz}$; spectrum lines - 1600 averages - 8.

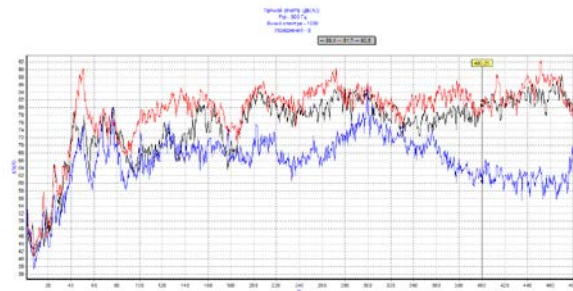


Figure 5. Direct spectrum – (dB(A)), $F_b = 800 \text{ Hz}$, Spectrum lines: 1600, Averages: 8.

As seen from obtained direct spectrum, the red spectrum (corresponding to the already formed crack) has a clear excess of the level ranges from 40 to 180 Hz, from 240 to 280 Hz, from 330 to 390 Hz and so on.

In order to reduce the probability of error, it is necessary, after detecting a deviation in the spectrum, to conduct repeated measurements. And only on the basis of repeated measurements, to make conclusions about the state of the equipment.

One of the cracks, which was detected by analyzing the direct spectrum of vibration shown in Fig.6.



Figure 6. The photo of the real welded gearwheel, with the cracks. As can be seen, due to this method, was sufficiently prevented a serious accident and were spared a lot of resources.

Conclusions

Vibration diagnostics of metallurgical or any rotating equipment is very important. This makes it possible to significantly reduce the costs of the equipment, to extend the term of its operation, as well as to improve the quality of products. The company must have a diagnostic service that provides vibration monitoring and forecasting the state of the equipment. It is also necessary to establish the system of remote monitoring equipment. The cost of equipment and software for the diagnosis is usually recouped within a year at its regular use.

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BOUSINESQ'S PROBLEM IN THEORY OF ELASTICITY AND ULTRASONIC

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Abstract : The evaluation of yield stress - σ_S is frequently encounter in material testing. In this method there is necessity of manufacture of test-tube from tested material or detail and made tension test. There is destructive method. For many details there is not acceptable. In material testing there is interest to non-destructive evaluation of yield stress σ_S for the materials and details. In this paper is lock at possibility for non-destructive evaluation of yield stress σ_S by means measure Brinel,s hardness – HB or velocities of propagation of longitudinal and transversal ultrasonic waves - V_L and V_T in tested materials and details.

KEY WORDS: NON-DESTRUCTIVE EVALUATION OF YIELD STRESS, VELOCITIES OF PROPAGATION OF ULTRASONIC WAVES

1. INTRODUCTION

The evaluation of the technological characteristics yield stress - σ_S is frequently encounter in material testing [1]. In this method there is necessity of manufacture of test-tube from tested material or detail and made tension test. There is destructive method. For many details there is not acceptable.

In material testing there is interest to non-destructive evaluation of yield stress σ_S for the materials and details.

In this paper is lock at possibility for non-destructive evaluation of yield stress σ_S by means measure Brinel,s hardness – HB or velocities of propagation of longitudinal and transversal ultrasonic waves - V_L and V_T in tested materials and details.

2. CONTACT BOUSSINESQ'S PROBLEM

The contact Boussinesq's problem in theory of elasticity [2,3,4] in follow. Let the surface $x_1 x_2$ is loaded with force F by sphere with diameter D (fig.1). The stresses $\{\sigma_{ij}; i, j = 1, 2, 3\}$ and displacements $\{u_i; i = 1, 2, 3\}$ is necessity to determined.

In particular, displacement $u_3(0)$, in contact point, is $u_3(0) = \frac{1}{4\pi} \left(\frac{1}{\mu} \cdot \frac{\lambda + 2\mu}{\lambda + \mu} \right) \frac{F}{d/2}$ [1], where λ, μ - Lamé's coefficients [1,6].

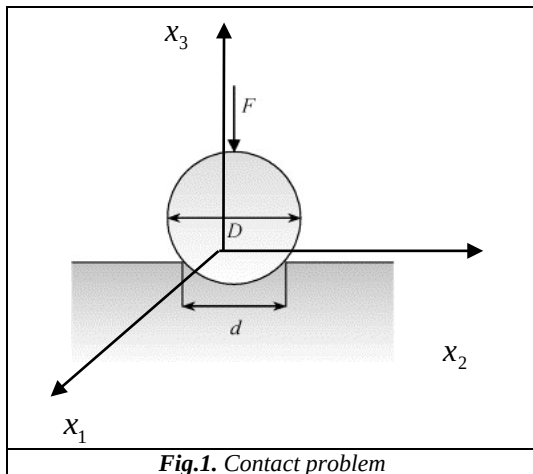


Fig.1. Contact problem

In Brinel's testing [4] the conditions there are [1]:

$$\frac{P}{D^2} = 30; D = 10\text{mm}; \frac{d}{D} = \frac{2}{5}. \text{ Therefore}$$

$$u_3(0) = \frac{375}{\pi} \left(\frac{1}{\mu} \cdot \frac{\lambda + 2\mu}{\lambda + \mu} \right).$$

From the stresses $\{\sigma_{ij}; i, j = 1, 2, 3\}$, there is the [2,3]

$$\tau_{\max} = \frac{1}{2} \varphi(\nu) HM, (Bousinesq) \quad (1)$$

$$\varphi(\nu) = \frac{1}{2} (1 - 2\nu) + \frac{2}{9} (1 + \nu) [2 \cdot (1 + \nu)]^{1/2}$$

HM is Maier's hardness. $HM = \frac{F}{S}$, where F – load, S – area of

circle of impress in area $(x_1 x_2)$, $S = \frac{\pi \cdot d^2}{4}$. The relationship

between HM and Brinel's hardness HB is $\frac{HB}{HM} = 1 - \Psi$, where

Ψ - steppe of deformation in impress [4]. In general $\Psi = \Psi\left(\frac{d}{D}\right)$ and therefore $HB < HM$. If $\frac{d}{D} < \frac{2}{5}$ ($\Psi < 3\%$) then

deferent between HB and HM is $\sim 3\%$. Therefore

$$HM \approx HB \quad (2)$$

If introduce the sphere in area $(x_1 x_2)$ there is elastic-plastic contact (fig.1). There is Treska's condition [5]

$$\tau_{\max} = \tau_S = \frac{1}{2} \sigma_S \quad (3)$$

In this case the relationship (1) reduce to

$$\sigma_S \approx \varphi(\nu) HB, (Bousinesq) \quad (4)$$

In experimental verification he yield stress σ_S calculated by (2) is not acceptable. There is necessity from condition for agreement of

experimental data with (2). To introduce coefficient K_{AGR} . In this case the (2) reduce to

$$\sigma_S \approx K_{AGR} \varphi(\nu) HB_{(Bousinesq)} \quad (5)$$

For steel with %C ~ 0.15 the data from mechanical test are: $HB^{MT} = 1430 \text{ MPa}$, $\sigma_S^{MT} = 255 \text{ MPa}$, $\nu = 0.28$ [7] i.e. $\varphi(0.28) = 0.67$. Therefore

$$K_{AGR} = \frac{1}{3.75} \approx \frac{1}{4}.$$

3. BRINEL'S HARDNESS

In material science Brinel's hardness HB is define by [1,4]

$$HB = \frac{P}{\pi \cdot D \cdot u_3(0)} \quad (6)$$

Put the test condition and the displacement $u_3(0)$ in (6) and Brinel's hardness is

$$HB \approx \frac{4}{5} \left(\mu \cdot \frac{\lambda + \mu}{\lambda + 2\mu} \right) \quad (7)$$

Relationship between Lamé's coefficients - λ, μ and velocities of propagation of longitudinal and transversal ultrasonic waves - V_L and V_T [ASTM E 494-92] is [6]

$$\lambda + 2\mu = \rho V_L^2; \mu = \rho V_T^2 \quad (8)$$

There is relationship between Lamé's coefficients - λ, μ and Young's modulus - E and Poisson's ratio - ν

$$\lambda = a_\lambda(\nu) E; \mu = a_\mu(\nu) E \quad (9)$$

where $a_\lambda(\nu) = \frac{\nu}{(1+\nu)(1-2\nu)}$, $a_\mu(\nu) = \frac{1}{2(1+\nu)}$. As for carbon steels the Poisson's ratio is written in a relatively narrow range, namely $0.23 \leq \nu \leq 0.32$, it can be considered an average value of $\nu \approx 0.28$. In this sense, in the parameters $a_\lambda(\nu)$ and $a_\mu(\nu)$ from (9) are constants, i.e. $a_\lambda(\nu) \equiv a_\lambda$ and $a_\mu(\nu) \equiv a_\mu$.

Density distributions $p(\lambda)$ and $p(\mu)$ of the random values λ and μ are obtained from the theorem of density functional distribution of dependent random value (Probability Theory) and applied to the dependencies:

$$p(\lambda) = \frac{1}{a_\lambda} p(E); p(\mu) = \frac{1}{a_\mu} p(E) \quad (10)$$

$$\text{where } p(E) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(E-a)^2}{2\sigma^2}\right)$$

The mathematical expectation and the dispersion of the random values λ and μ are given in:

$$\mathbf{M}(\lambda) = a_\lambda \mathbf{M}(E); \mathbf{M}(\mu) = a_\mu \mathbf{M}(E) \quad (11)$$

$$\mathbf{D}(\lambda) = a_\lambda^2 \mathbf{D}(E); \mathbf{D}(\mu) = a_\mu^2 \mathbf{D}(E) \quad (12)$$

Density distribution $p_{HB}(HB)$ is calculated by

$$p_{HB}(HB) = \frac{1}{2} (HB)^{-1/2} p_\mu((HB)^{1/2}) \quad (13)$$

4. EQUIPMENT AND MEASURING IN NDE

The following technical tools (SONATEST, England, PANAMETRICS, USA) are used for measurements velocities of ultrasonic wave propagation through investigated materials and details:

- Digital ultrasonic flaw detector SITESCAN 150S (SONATEST, England). The measurements are carried out by means option "measurement of time propagation of ultrasonic wave" with accuracy 0.01 μs .
- Calibration block - CBV with $V_L = 5.93 \text{ mm}/\mu\text{s}$ (SONATEST, England).
- Transducers with X-cut of piezo-electric element (for longitudinal waves, fig.4. and Y-cut of piezo-electric element (for transversal waves, fig.5. and frequency 5 MHz.



Fig.4. Transducers with X-cut of piezo-electric element



Fig.5. Transducers with Y-cut of piezo-electric element

A digital micrometer for thickness measure (Digimatic Micrometer, Range 0-30 mm, Accuracy 0.0001 mm (f. Mitutoyo - Japan) is used also.

The values of the "unknown" velocity of longitudinal and transversal ultrasonic wave $V_X \equiv (V_L; V_T)$ in $\text{mm}/\mu\text{s}$ is calculate by

$$V_X = \frac{l_X}{T_X / 2} \quad (14)$$

where $T_X \equiv (T_L; T_T)$, μs are the values of the "unknown" time of propagation of longitudinal and transversal ultrasonic wave, l_X - is the thickness of the studied specimen in mm.

Presentation of velocity measurement of V_L and V_T .

The relative error for velocity $\frac{\Delta V_{L,T}}{V_{L,T}}$ is

$$\frac{\Delta V_{L,T}}{V_{L,T}} = 2 \cdot \left(\frac{\Delta l}{l} + \frac{\Delta t_{L,T}}{t_{L,T}} \right) \quad (15)$$

where $\Delta V_{L,T}; \Delta l; \Delta t_{L,T}$ - absolute errors respectively for velocity, thickness, time. Confidence interval for measure velocity is

$$\overline{V_{L,T}} \pm \left(1 + \frac{1}{n} \right) T(n; \alpha) S_{V_{L,T}} \quad (16)$$

where $\overline{V_{L,T}}$ и $S_{V_{L,T}}$ are respectively mean and standard deviation for measure velocity, n – number of readings, $T(n; \alpha)$ - Student's distribution in probability $\Pr = 1 - \alpha$.

5. CONCLUSION

The solution of Boussinesq's problem in theory of elasticity is analyzing and obtained the relationship $\sigma_s \approx \frac{1}{4} \varphi(\nu) HB$, who is agreement with experimental data. The functions $\nu(V_L; V_T)$ and $HB(V_L; V_T)$ are known.

For non-destructive evaluation of yield stress σ_s by means measure of velocities of propagation of longitudinal and transversal ultrasonic waves - V_L and V_T in testing materials and details is derivate.

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INTERNATIONAL TRANSPORT PROJECTS AND ECOSYSTEM OF BLACK SEA

МЕЖДУНАРОДНЫЕ ТРАНСПОРТНЫЕ ПРОЕКТЫ И ЭКОСИСТЕМА ЧЕРНОГО МОРЯ

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Abstract: *The importance of the Black Sea for modern Georgia is invaluable. It represents one of the important natural formations for the common geographical location of the country, resource potential, the main artery of recreational zone and foreign relations. Therefore, the security, economic welfare and future in general depend on effective use of economic potential of the Black Sea and its ecological condition.*

The article deals with the ecological condition of the main problems of the Black Sea. Special attention is paid to international transport and energy projects. It is proved that the projects that have been implemented and planned the "Blue Stream" and "South Stream" (so called "Turkish Stream") represent potential threats to the Black Sea in terms of environmental deterioration. Modest conclusions are made in the article concerning the joint efforts of the Black Sea countries directed to support transport and energy projects, realization of which will impact ecological condition of the Black Sea. In the opinion of the authors, the "Nabucco" project represents the very transport-energetic project.

KEY WORDS: ECOSYSTEM OF THE BLACK SEA, "NABUCCO" PROJECT, ECOLOGICAL CONDITION OF THE BLACK SEA

1. Introduction

The importance of the Black Sea for modern Georgia is invaluable. It represents one of the important natural formations for the common geographical location of the country, resource potential, the main artery of recreational zone and foreign relations. Therefore, the security, economic welfare and future in general depend on effective use of economic potential of the Black Sea and its ecological condition.

The Black Sea has an area of 422,000 km², the longest east-west extent is about 1,167 km (Burgas-Kobuleti), a maximum width - 580 km, a maximum depth – 2211 m, the coastline is approximately 4000 km, 320 km of which belongs to Georgia (Russian Federation – 395 km, the Ukraine – 1340 km, Romania – 215 km, Bulgaria – 317 km, Turkey – 1365 km).

A net outflow of water reaches 200 km³ per year through the Bosphorus. Inflow of freshwater from the surrounding areas reaches 320 km³ per year, the majority of which comes from central and central-eastern Europe [1].

So called oxygen rich "organized" layer of the Black Sea extends to the depth of 175-200 m, from 200 m up to the bottom it is almost without oxygen and there is no organic life there. Outstanding features of the Black Sea, distinguishing it from the rest of the hydrosphere of the earth, represent original layering character. Surface layer which is 175-200 m thick stands out with its density (it is lighter) from water body. This difference is so clear that confusion between layers of water is almost impossible. That's why deep water is accumulated with huge quantity of H₂S.

The Black Sea is one of the biggest locked water masses that does not stand out from the complex features and is convenient for navigation. Therefore, the Black Sea is the most important transport corridor [2].

2. Preconditions and means for resolving the problem

In 1960-ies of XX century intensive involvement of humanity in ecosystem of the Black Sea, in particular excessive use of the Black Sea resources, unplanned urbanization in the coastal zones, invasion of series of exotic and pathogenic organisms ballast water through the ballast waters, building of dams on many rivers, huge number of constructions to protect the coastlines, unduly cleaned wastewater spill (ships, industry and coastal areas of the settlements and their improper caring), the growth of illegal fishing and many other reasons have led to the degradation of the Black Sea ecosystem. Natural features of the Black Sea make this process

even more difficult. Exchange of the Black Sea water to the Mediterranean Sea water is extremely slow. Its salinity is less than 20 per mille. There are no revolutions and reversing in the Black Sea, in the contrary to other seas (the Baltic Sea). As a result, there is very little oxygen in it and contaminants are collected in abundance. Water is actually stopped; as a result oxygen is only in upper layers. Healthy seas need the oxygen not only for living organisms, but also for putrefaction and decomposition of dead plants and dead animals.

Black Sea and its resources are in greatest danger. It is almost completely locked and probably the most polluted seas in the world due to the fact that the pool is much beyond the scope of the six countries bordering the sea, and 17 countries are involved in the contamination. The only linking of the sea to the world ocean is Bosphorus Strait. At the same time it receives waste water and other pollutants from such large rivers as the Danube, Dnepr, and elevation, as well as from many other smaller rivers. Hence, it is understandable that protection of the Black Sea is possible only with the joint efforts and international assistance.

Currently, the Black Sea is facing the following main problems:

- Nitrogen and phosphorus compounds;
- Sewage Water;
- Toxicants;
- Radioactive materials;
- Invasive species of living organisms
- Raw refuse and oil pollution;
- International transport and energy projects.

One of the important problems mentioned above is international transport and energy projects. A highly favorable coastal location of the Black Sea has always been a certain advantage for development of transport industry, especially in recent period, when there have been many economic changes in the region. The location means many advantages and disadvantages for the region located on the crossroad of Europe and Asia: on the one hand it is its a favorable condition for the development of trade, but its' necessary to establish a certain balance firstly between the current favorable economic profit and on the other hand increasing, long term development of the native population and environment. Transportation of the oil in the Black Sea region in a part of this kind of danger, especially if the social and environmental issues are left by the wayside, and the geopolitical importance of the arguments prevail importance of future decisions. In recent period the issue of international importance is energy supply of Europe. Many projects are being developed, which provide energy to improve the energy supply through diversification of routes and

sources. This kind of route crosses the Black Sea and poses serious threats for the Black Sea from the ecological point of view. If the Black Sea performed only the navigational function in the past, in recent years it gained the new function – one pipeline has already been built and some more pipelines are planned to be built on the grounds of the Black Sea. Particularly [3,4]:

The Blue Stream. Mentioned project is considered as the deepest pipeline in the world, the total length of the pipeline is 1240 km, which started operations in 2006. The land section consists of the Stavropolskaya and Krasnodarskaya compressor stations. The offshore section is 396 kilometers long laying from the Beregovaya compressor station in Arkhipo-Osipovka to the Durusu terminal locating 60 kilometers from Samsun (Turkey).

"South Stream" and "Turkish Stream". "South Stream" is an abandoned project running into 10 milliards to transport natural gas of the Russian Federation through the Black Sea to Bulgaria and through Serbia, Hungary and Slovenia further to Austria. According to the project 2000 km long pipeline was to start from Varna and run to Pleven. From there, the original southwestern route was to continue through Greece and Ionian Sea to southern Italy. The newer northwestern route would have continued from Pleven to Serbia. In Serbia, then running through Zaječar and Paraćin to Čenta. From Čenta the main pipeline would have continued in direction of Gospodinci while branch-off line would run to Republika Srpska in Bosnia and Herzegovina. Construction of the Russian onshore facilities for the pipeline started on December 7, 2012 by "GAZPROM" [5,6]. The last developments in the Ukraine lead the project in danger. That is why, at the end of 2014, Russia decided to suspend the "South Stream" and instead of it started so called "Turkish Stream" pipeline. The Turkish Stream is a working name of the proposed natural gas pipeline from Russia to Turkey across the Black Sea. The proposal was announced by Russian president Vladimir Putin on 1 December 2014, during his state visit to Turkey. The pipeline would start at Russkaya compressor station near Anapa. The landing point in Turkey is not negotiated yet. According to Gazprom, pipe-laying works will start immediately when the landing point in Turkey is decided. The mentioned projects constitute potential threats to the pollution of the Black Sea, hydrogen sulfide gas, which is considered as corrosive substances is poisonous and causes rapid corrosions of metal. Therefore, on the one hand, the efforts of the Black Sea countries should be implemented to the strict monitoring of the proper operations of the pipeline, on the other hand, active support of the alternative projects linking to the Black Sea. To our opinion The Nabucco Pipeline is this kind of alternative project.

"The Nabucco Project" aims to run the gas obtained in Caspian region and Central Asia to Europe through Georgia and Turkey. Preparations started in 2002, the building of the pipeline was planned to start in 2011 and finish in 2014, but because of the problems with gas supplier countries the realization of the project was postponed several times. In 2011 it was announced that enforcement of the project was postponed until 2018. However, on 28 June 2013 Shah Deniz consortium announced that it had chosen the Trans Adriatic Pipeline over Nabucco for its gas exports,

Nabucco, is the idea born on the interests of the European Union and US, while South Stream project was created and supported by political leadership of Russia, hence Russia has done everything to ensure that this project is not implemented and partially succeeded in it.

Judging from the economic and technical parameters, "Nabucco" is more interesting project than "South Stream". Implementation of "South Stream" (including the "Turkish Stream") and blocking "Nabucco" allows Russia to influence the prices of natural gas supply not only in Europe, but also supply of Europe with gas from the Caspian Sea countries (Turkmenistan, Azerbaijan, Kazakhstan, Uzbekistan) as well. Moreover, unlike the Persian Gulf countries (which deliver natural gas in tankers to European terminals), but the pipeline, they don't have no other means of supply of natural gas.

The main advantages of the "Nabucco" in comparison to "South Stream" is as follows:

- Reduces dependence of Eastern European countries on Russia;
- The project is open to several transit suppliers, ensuring competition and, therefore, protects consumers from monopolistic pricing;
- Encourages the utilization of new deposits, as Europe is the most expensive natural gas market in the world.
- Encourages trans-Caspian pipeline, which will break the path for a large natural gas resources of Turkmenistan, Uzbekistan and Kazakhstan to European markets, bypassing Russia and contribute to the growth of their political independence;
- Technically easier to implement, its operation will be relatively cheap and economic parameters are better;
- The most important issue is to reduce the risks and threats that are associated with the deterioration of the ecological conditions of the Black Sea [7].

Another problem in terms of the ecological state of the oil extraction works. Such work is already being planned. Another problem in terms of the ecological condition is commencement of crude-oil production. These kinds of works are already planned and do not bode well for the Black Sea. If the industrial production of oil starts, it will have a very large impact on the Black Sea, because the biggest problem is not the "big discharge", but also the so-called "daily discharge". "The Black Sea Convention" can be considered as a step forward in terms of protection of the Black Sea. The convention was signed in Bucharest in April 1992, and ratified by all six legislative assemblies of the Black Sea countries as of Bulgaria, Georgia, Romania, Russia, Turkey and the Ukraine. The countries acknowledge the increasing deterioration of the environment in their joint resources in the Black Sea which caused signing of Convention on the Protection of the Black Sea against Pollution (also so called the Black Convention or the Bucharest Convention). On 31st October 1996, Bulgaria, Romania, Russia, Georgia and Ukraine's Ministers of Environment met in Istanbul, where they signed the Strategic Action Plan for the Protection of the Black Sea, the most comprehensive program, which is to save the world's one of the most polluted seas.

3. Conclusion

It can be said that currently there are plenty of other economic projects in the Black Sea countries, which are a potential threat from the ecological point of view. As for the ecological projects enhancing reduction of the pollution of the Black Sea, are very small. Besides, there are no states safe from the adverse effects of pollution on human health effects or country's economy. Therefore, the joint efforts of the Black Sea countries should be directed to such projects, including support of transport and energy projects, realization of which will have minor impact on the ecological situation in the Black Sea.

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CAD SYSTEMS IN KOSOVO MANUFACTURING INDUSTRIES: THE CASE OF KOSOVO FURNITURE INDUSTRY

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Abstract: *In Kosovo enterprises, the usage of CAD systems are limited, in the beginning as a result of higher prices of hardware and software equipment and afterwards as a result of the war events that Kosovo and their economy passed. This paper reports the results and conclusions drawn from a questionnaire survey concerning the use and implementation of computer-aided design (CAD) in the Kosovo furniture industry.*

It was regarded as important to find out what impacts implementation has on the usage of CAD and whether companies in the furniture industry think the use of CAD could improve their product development. Less than half of all product-developing companies in the Kosovo furniture industry are using CAD today. The study found that the following factors are involved in successful implementation: management support, realistic budgeting, selection of system and effective, company-specific training. Most CAD users are satisfied with their system and think that it fulfills their needs. Many of the difficulties referred to by respondents can be related to the implementation phase, and they could be avoided. In general, the furniture industry considers that CAD improves their product development work.

Keywords: CAD SYSTEMS, KOSOVO INDUSTRIES, MANUFACTURING, FURNITURE INDUSTRY, 2D AND 3D CAD.

1. Introduction

The Kosovo furniture industry, like other industries, has become exposed to greater competition, and market size has increased especially after the war in 1999. During the war years (1998-1999), production in Kosovo was to high scale destroyed and was almost non-existing. Monitoring of major world technological developments that occurred during this time has been difficult in these conditions or nearly impossible. In the years after the war in the market of Kosovo were noticed efforts towards the development of small and middle business. Large businesses have been developed in a very small measure.

"New technological developments and market demands have major impacts on manufacturing" [Osita, 2002, p.19]. Process of manufacturing is a complex that includes some phases, starting with evaluating the market and investigating the demands of customers for a product, and ends with delivery of the actual product. Successful enterprise should take into account the factors that affect current and future demands for a product. It provides management with appropriate inputs for decision making and directing resources of a company toward production of a part that is needed in the market. [2, 2002]

Customers have raised demands for short delivery time, improved quality, and low prices. Thus, the furniture industry has to improve its way of developing products and services. In the view of Hoff et al. (1997), companies (wood-products manufacturers) must respond, and advanced technologies might be one way of responding to changing conditions and requirements for competitiveness. This implies that computer-aided design (CAD) can make a contribution to the way in which products are developed.

This paper presents the results of a questionnaire survey on the implementation and use of CAD in the Kosovo furniture industry. Its goals were to investigate how far the Kosovo furniture industry has progressed in the use of CAD in product development and how implementation has been performed. It also investigated what impacts implementation has on the usage of CAD, and whether companies in the furniture industry think that the use of CAD could improve their product development. The purpose with the investigations was to build knowledge on a branch level on how to increase the competitiveness within the furniture industry.

2. Statement of the problem

Production is directly related to the market, and an advanced production enables other businesses dealing with industry. To meet the demands of the customer it is required to produce high quality products, and this is achieved by applying modern production technologies and processes that accompany it. [3, 2008]

In many industries CAD usage is concentrated on product engineering and for programming computer numerical control (CNC) machinery. In many companies, the use of CAD within product engineering is restricted to its function as a drafting tool. Yet CAD, and solid modeling in particular, has a potential that far exceeds simply automating the drafting process. "The transition from the use of CAD as a drafting tool for producing parts sketches for route sheets to a tool for creating virtual models of complete furniture pieces means a rethinking of how CAD is integrated into product engineering" (Wiebe and Summey 1997).

Another aspect of the implementation and use of CAD is that the technique does not make a company more efficient if its organization and product development are not changed at the same time. Applying a new technology is not just a matter of changing equipment or systems. How advanced the technique needs to be is also related to the company's needs, organization, and work methods (Forslin 1988). Also, Schaffitzel and Kersten (1985) write that the potential of CAD and its integrative effects demand new organizational rules, and that the overall procedural system within the company must be considered.

3. Objectives and purpose of the study

This paper presents the results of a questionnaire survey on the implementation and use of CAD in the Kosovo furniture industry. Its goals were to investigate how far the Kosovo furniture industry has progressed in the use of CAD in product development and how implementation has been performed. It also investigated what impacts implementation has on the usage of CAD, and whether companies in the furniture industry think that the use of CAD could improve their product development. The purpose with the investigations was to build knowledge on a branch level on how to increase the competitiveness within the furniture industry. The assumption that new technology in product development is a competitive factor bases

the investigations. Also implied is that knowledge on how to efficiently implement new technology is needed.

The overall objective and purpose of this study are: to determine the scale of application of CAD systems in Kosovo furniture industry, and also to try to identify challenges that influence the implementation of CAD systems.

The purpose is to possess knowledge about CAD systems, their usage and influence in industry especially in furniture industry, so that managers and engineers and others have an easier access to integrate these systems in industry.

4. Methodology

To obtain data about the application of CAD systems in Kosovo furniture industry we have chosen questionnaires and interviews with the staff of enterprises.

The questionnaire was designed to provide a description of usage and implementation of CAD systems in Kosovo industry. Questionnaire administration offers a suitable method for posing an equivalent set of questions to some number of people.

The questionnaire comprised 13 items, subdivided into 4 sets that cover one part of the goals and purpose of the study:

1. * Company description;
2. * CAD systems usage in the furniture industry;
3. * Implementation of CAD;
4. * CAD systems in use, actual and future needs.

The questions were grouped in order to make it easier for the respondents to work through the questionnaire. Items for each topic were also divided into three categories: questions of fact, questions about opinions and beliefs, and questions about behavior (Gillham 2000). Most of the items were questions of fact, and appeared first in every topic group. The reason for placing them first in each category was that they are normally easy to answer. A majority of the questions were multiple-choice and closed-types, while a few were scale questions, both answered by checking tick-boxes. There were also a few open-ended questions.

Questionnaires were sent through the companies personally and at the same time are held interviews with staff of organizations, including different categories of personnel who are associated with the production process and management of enterprises in order to gather as much information about CAD systems to fulfill the objectives and purpose of the study. From 125 distributed questionnaires, 105 were filled out and returned.

5. Results and discussion

In this research are included 15 companies. Based on the analyses of answers to questions of the questionnaire shows that, from 15 inspected companies, four of them are using CAD systems or 26.6%, 6 are partially using CAD systems, or 40.00% and 5 others have not yet introduced this technology in their organization or 33.33%. In figure 5.1 is shown a graphically scale of application of

CAD systems in organizations involved in this research. This research is done during the year 2014.

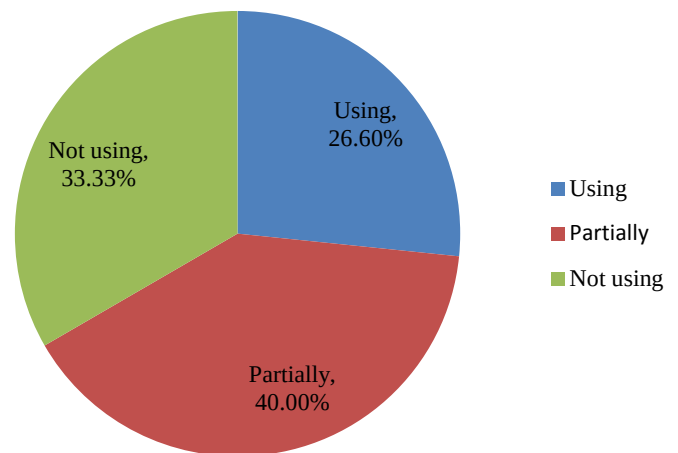


Figure 5.1 Scale of application of CAD systems in organizations involved in this research.

The results of this paper will be compared with the results of research of Riinvest Institute that has done in 2009 about the application of new technology in the industry of wood as well as results of research that we have done during the years 2010-2011 about the application of CAD/CAM systems in Kosovo enterprises, the research which is presented at The International Program Committee of the 9th International Congress "MACHINES, TECHNOLOGIES, MATERIALS'12" (Mr.sc. Dipl.-Ing. Fatmir AZEMI, Mr.sc. Dipl.-Ing. Gani Pllana: "SCALE OF APPLICATION OF CAD/CAM SYSTEMS IN KOSOVO ENTERPRISES" 19-21th September 2012 Varna-Bulgaria, ISSN: 1313-5031.

In figure 5.2 and 5.3 graphically are presented research as mentioned above

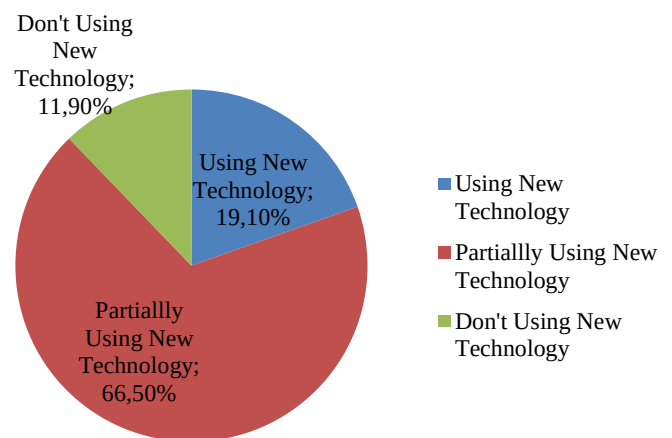


Figure 5.2 Scale of application of new technology in Kosovo wood industry – Institute Riinvest 2009.

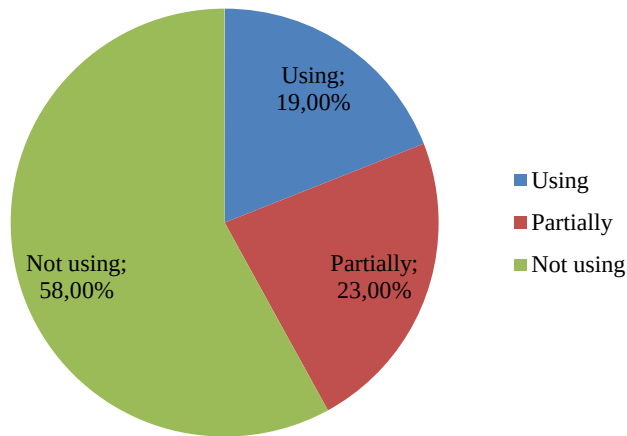


Figure 5.3 Scale of application of CAD /CAM systems in Kosovo enterprises.

6. Conclusion

Based on the analyses of answers taken from the questionnaire we could conclude that less than half of all product-developing companies in the Kosovo furniture industry are using CAD systems today. Based on the interviews with managers of companies, engineers and staff like that, the study found that the following factors are involved in successful implementation: management support, realistic budgeting, selection of system and effective, company-specific training.

From 15 inspected companies, four of them are using CAD systems or 26.60%, six partially are using CAD systems, or 40.00% and five others have not yet introduced this technology in their organization or 33.33%. Compared to the results that have been done in the years 2009-2011 we can see a considerable increase in the application of CAD systems in Kosovo furniture industry.

Most of the responding companies in the Kosovo furniture industry that use CAD are satisfied with their system and think that it fulfills their needs. Many of the difficulties referred to by our respondents are related to the implementation phase, and can be avoided. Nevertheless, the furniture industry as a whole considers that CAD improves their product development work

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ERGONOMICS IN E- LEARNING

ЕРГОНОМИЯ В ЕЛЕКТРОННОТО ОБУЧЕНИЕ

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Abstract. *E-learning, seen in the ergonomic aspect, is a complex and intense human activity that is subject to investigation and analysis in order to optimize it. The quality of education is seen as a trinity of its effectiveness, efficiency and satisfaction - criteria that are defined, studied and assessed using a specially developed, original methodology of the authors. These criteria were used to investigate BA, MA and Ph.D. students in two consecutive years.*

Keywords: *E-LEARNING, ERGONOMIC RESEARCH, EFFECTIVENESS, EFFICIENCY, SATISFACTION.*

Introduction

In today's information society based on knowledge and intellect, education plays a fundamental role in the professional training of each individual. The rapid advent of electronic (information and communication) technology is completely changing the educational context. Traditional learning, implying one-way transfer of knowledge from teacher to student (top-down) is no longer sufficient. Students have to prepare for autonomous life-long learning through cooperation and interaction with the teacher. E-learning has the potential to change the way we teach and learn. It provides new opportunities for customizing the learning process and makes prerequisites to enrich the learning experience and the quality of learning. E-learning can not replace teachers, but in combination with the existing traditional methods, it can enhance the quality and enrich their teaching practice. In a more general sense, blended learning is characterized by the upgrade, incorporation, integration of various information and communication technologies in traditional educational settings. [7, 8]

The advent of e-learning has enormously increased the motivation of learners to participate in the learning process; classes and knowledge are becoming more experimental and attractive. New values, skills, competencies are being cultivated. Creativity is being stimulated, original decisions are being made and communication at all levels is being improved, including the skills to use information and computer technologies. [1, 2]

Training students, like every other human activity, can be optimized, and this requires its permanent monitoring and evaluation. Ergonomics is the scientific direction aimed at continuous improvement of human activities. The ergonomic evaluation of the activity is carried out under the following criteria: achieving excellence in labor (effectiveness) while preserving the health of everyone with minimal psychological, physiological risks, saving time and finances (efficiency) and providing the necessary conditions and facilities so that the Man feels satisfied. [3, 6]

Prerequisites for the solution of the problem

The effects of the introduction of electronic technologies can be evaluated by the help of ergonomic criteria: effectiveness, efficiency and satisfaction. [4]

The effectiveness of e-learning consists of more successful (than traditional training) solving learning tasks such as acquiring knowledge and skills through free and easy access to educational and scientific information, successful preparation and self-preparation for exams, writing course projects, theses as well as participation in research projects and forums.

Efficiency takes into account factors such as: reducing the time to prepare for exams as well as for completing educational and scientific tasks; saving resources material and non-material plan (psychological, medical, social). Briefly, the efficacy of e-learning means to achieve good results coupled with a minimum expenditure of time, mental, financial, etc. resources.

Satisfaction with e-learning is a subjective assessment, which includes demonstrated confidence, activity in school and outside school activities and general contentment with the obtained results.

Solution of the problem

E-learning at UCTM is at the stage of gradual introduction. Its share in the traditional forms of education: lectures, seminars, laboratory work is still relatively small. The software products for self-learning and self-control are also insufficient. On the other hand, there is a strong motivation of students to learn in an electronic environment. [5] Furthermore, in recent years, university management has been investing seriously in refurbishing computers, developing e-learning platforms, making electronic libraries, expanding access to various databases, buying specialized software to assist in designing course and graduation projects.

In view of the above, the investigation of the effectiveness, efficiency and satisfaction of the introduction of electronic technologies in education at UCTM was performed using a specially developed for this purpose Ergonomic card among BA, MA and PhD students in two consecutive years.

In order to evaluate effectiveness, the view of the trainees was sought for, concerning their expectations on the wider introduction of electronic technologies in traditional forms of education: namely in lectures, seminars, laboratory work; to increase the opportunities for self-learning, self-control, and ultimately for final evaluation and test. These are the main directions of electronization that lead to effective improvement of education- its modernization, upgrade and integration with traditional technologies.

In order to evaluate efficiency, the assessment of trainees on existing university facilities was asked for: hardware (sufficient number of computers and multimedia in the halls) database software (free access to Internet, a sufficient number of programs for self-learning, self-control, availability of specialized software for engineering research , projects and theses). Positive evaluations on these matters are important prerequisites for achieving high efficiency of training i.e. achieving good academic results with a minimum expenditure of time, mental, financial, etc. resources.

As far as satisfaction is concerned, the respondents were asked to express their personal opinion about the quality of the computer equipment at the university, the stock of electronic library with academic and scientific information, access to various databases; they were also asked to assess the level of work with electronic technologies of their teachers and finally to assess their competence to work in WEB environment. Satisfaction with the introduction of e-learning is higher if there are material facilities and good psychosocial environment of the required standard.

Results and discussion

The results of the study of the effectiveness, efficiency and satisfaction with regard to the introduction of electronic technology in education are given in tables and graphs. Tables 1-3 and Figures 1-3 show the percentage [%] positive attitudes and evaluations of the three different groups of respondents: BA, MA, Ph.D. students according to the three ergonomic criteria. Tables 4-6 and Figures 4-6 show the percentage [%] positive attitudes and assessments of students in two consecutive years.

Table1. Assessment of effectiveness by groups of students in varying degrees of training

Effectiveness	Bachelor	Master	Ph.D. student
Lectures	97	100	100
Seminars	89	82	82
Laboratory Work	53	42	59
Self-education	94	86	94
Self-assessment	100	80	94
Examination	78	82	71

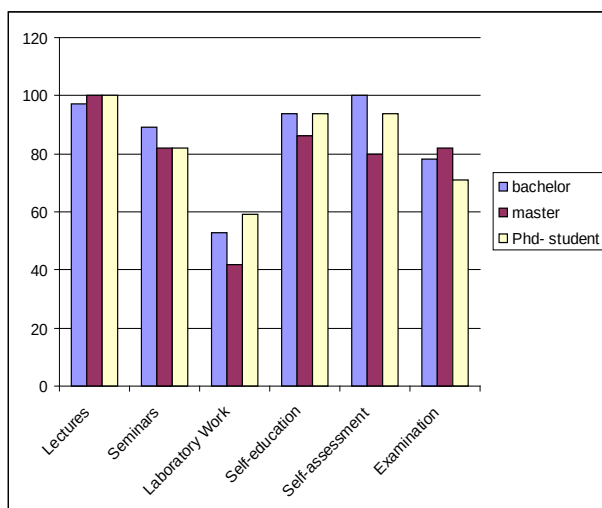


Fig.1. Assessment of effectiveness by groups of students in varying degrees of training

Evaluations of the effectiveness of e-learning show high positive motivation of the three groups of students on most indicators: students at UCTM welcome the introduction of new technologies to lectures, seminars, self-education. The students are reserved regarding their use in laboratory work and final control.

Table 2 Assessment of efficiency by groups of students in varying degrees of training

Efficiency	bachelor	master	Ph.d. student
Multimedia	93	92	96
Free Internet	70	87	88
Computers	88	88	88
Software engineering	61	77	78
Self-education	78	60	67
Self-assessment	70	56	62

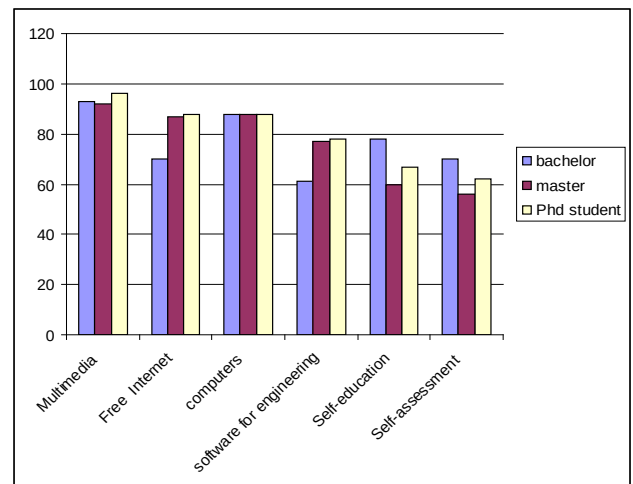


Fig.2. Assessment of efficiency by groups of students in varying degrees of training

The efficiency of the introduction of electronic technologies in education is reflected in the high ratings of the respondents for facilities: available computers, multimedia, access to Internet. There is much to be done in the direction of providing specialized software engineering research programs for self-study, self-control, especially for the groups of postgraduates.

Table 3 Assessment of satisfaction by groups of students in varying degrees of training

Satisfaction	Bachelor	Master	Ph.D. student
Quality computers	94	88	84
E-libraries	95	91	88
Database	89	90	87
Faculty competence	89	84	89
Students' competence in WEB	100	98	100

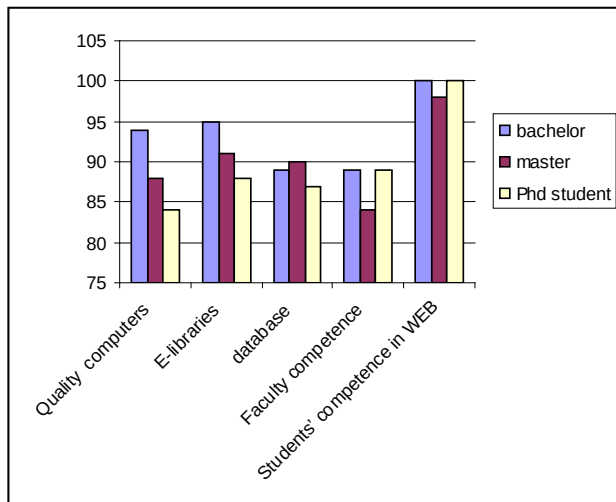


Fig. 3. Assessment of satisfaction by groups of students in varying degrees of training

Satisfaction with the introduction of e-learning for all the investigated groups was relatively good. As expected, the group of doctoral students (such as people with higher requirements and experience) give relatively low scores concerning quality of available computers, the available educational and scientific information in digital libraries, access to various databases. The high self-esteem of all the three groups concerning their work in WEB environment is very optimistic.

Table 4. Assessment of the effectiveness by years

Effectiveness	2014	2015
Lectures	94	97
Seminars	80	89
Laboratory Work	42	53
Self-education	86	94
SELF-ASSESSMENT	82	100
EXAMINATION	76	78

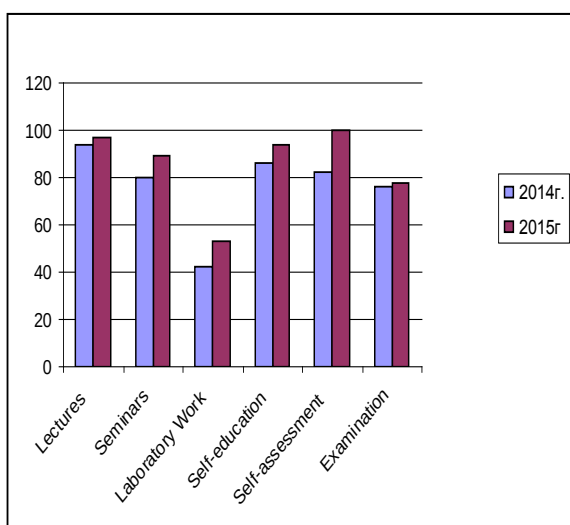


Fig. 4. Assessment of the effectiveness by years

Table 5. Assessment of the efficiency by years

Efficiency	2014r.	2015r.
Multimedia	91	93
Free Internet	85	70
Computers	89	88
Software for engineering	68	61
Self-education	64	78
Self-assessment	66	70

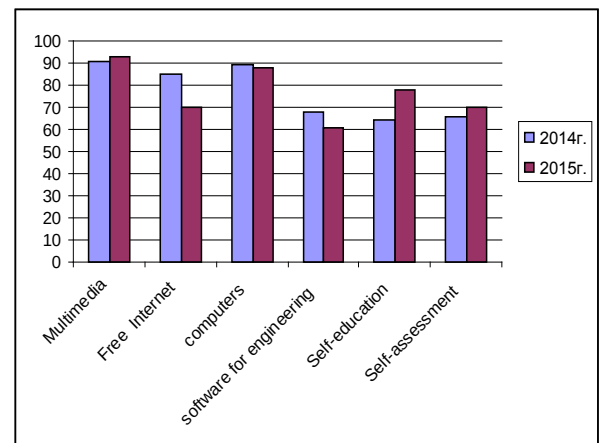


Fig. 5. Assessment of the efficiency by years

Table 6. Assessment of satisfaction by years

Satisfaction	2014r.	2015r.
Quality computers	66	94
E-libraries	88	95
Database	83	89
Faculty competence	67	89
Students' competence in WEB	100	100

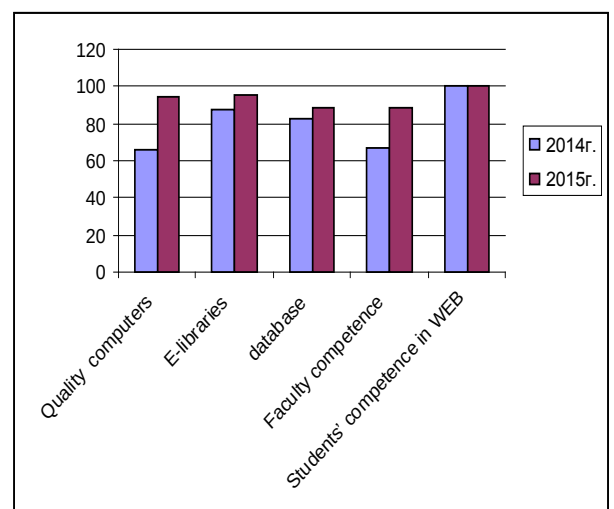


Fig. 6. Assessment of satisfaction by years

Findings and conclusion

There is a steady trend, expressed by the majority of students, to increase the share of E-learning, both in traditional forms of education: lectures, seminars, laboratory work, as well as for self-study, self-control, even for the final control.

Amid the growing desire for rapid development of electronic technology in engineering education, the students have more requirements concerning the availability of uninterrupted Internet access at the university, and the need for wider application of specialized software for engineering analysis and projects.

Positive trends in the field of E-learning can be identified according to the assessment given by students:

The share of high-quality computers at the University increases;

The capacity of the electronic library at the University increases;

The access to various databases increases;

The qualifications of the teaching staff are being evaluated more and more positively, amid the pronounced "excellent student training" to work in an electronic environment.

E-learning has been developing in the context of the information society, which "is not only related to the transmission of sound knowledge verified by tradition in successive generations, but it has the heavy task to teach the younger generation to deal with the chaotic and difficult to predict flow of knowledge, where the young must be able to "swim". E-learning is interactive and it provides great freedom of the learner in terms of means, place, time and rhythm of learning.

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